Dating a 20th-Century Fault, Elk Summit Talus Apron, Big Creek Area, Valley County, Idaho

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By B.F. Leonard *and* Roger Rosentreter

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Dating a 20th-Century Fault, Elk Summit Talus Apron, Big Creek Area, Valley County, Idaho

By B.F. Leonard[1] *and* Roger Rosentreter[2]

ABSTRACT

A young fault cuts obliquely across the talus apron near Elk Summit in central Idaho. Twenty-five or thirty years ago, the fault was marked by a bare, brown, east-trending scarp that slashed across talus covered with lichens. The scarp, extending several hundred meters from a hinge point near Elk Summit, showed at its east end a maximum displacement of about 1 m, south block down, scarp dip perhaps 60°–70° S. The scarp has since degenerated to a narrow, discontinuous bench on which the talus blocks have few lichens. Comparative lichenometry of *Rhizocarpon geographicum* and *Lecidea atrobrunnea* from talus blocks at Elk Summit and headstones in local cemeteries indicates that the fault formed sometime between the 1960's and the first decade of the century. Aerial photographs indicate that, though the fault may have begun to develop before 1946, its surface expression did not become conspicuous until sometime between 1954 and 1964. We believe that surface expression of the fault is earthquake related. No major earthquake epicenters have been reported from the Elk Summit area, but effects of the August 1959 earthquake at Hebgen Lake, Montana, were felt at an intensity VI (modified Mercalli scale) within 9–30 km of Elk Summit, 320 km distant from Hebgen Lake. Accordingly, the most likely date of the fault near Elk Summit is 1959.

STUDY AREA

A young fault cuts the talus apron near Elk Summit (fig. 1), a road pass at 2,643 m elevation in the Wolf Fang Peak 7.5-minute quadrangle, Valley County, Idaho. When Leonard, the senior author, first recognized the fault 25 or 30 years ago, it was marked by a conspicuous, bare, brown, east-trending scarp that slashed across talus covered with lichens. The scarp, extending several hundred meters from a hinge point about 100 m east of Elk Summit, showed at its east end a maximum displacement of about 1 m, south block down, scarp dip perhaps 60°–70° S. Leonard thought at the time that the growth rate of the large colonies of dark lichens might be useful for dating the fault, but, knowing little about lichens and feeling pressed for time to finish some geologic mapping, he failed to collect them or to photograph the fault scarp. When next he visited the area, in 1991, he found that the scarp had degenerated to a narrow, discontinuous bench, 1–2 m wide, locally showing small bits of brownish rubble as well as sparsely lichen bearing talus slabs of 1–3 dm size, a few larger blocks from relatively stable talus upslope from the bench, and a little talus derived from recent rockfalls. The inner edge of the bench was defined by an almost continuous train of meter-size and smaller talus blocks liberally covered with dark lichens. The train of dark blocks, unimpressive at close quarters, is clearly visible at a distance (fig. 2).

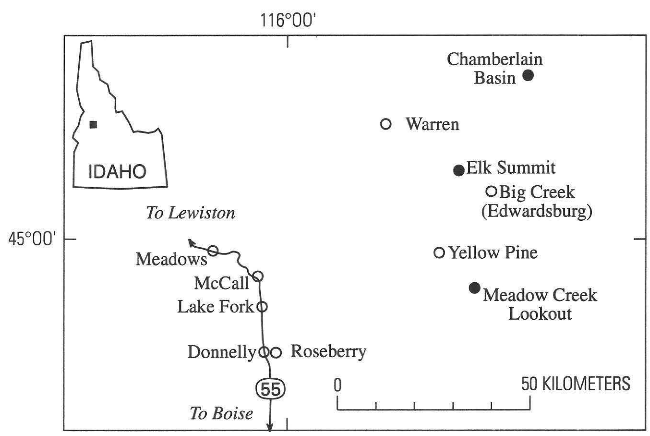

Figure 1. Index map to area of Elk Summit, central Idaho. Secondary roads not shown. Open circles represent settlements; filled circles indicate other geographic features.

[1]U.S. Geological Survey, MS 905, Box 25046, Federal Center, Denver, Colorado 80225.

[2]Bureau of Land Management, 3380 Americana Terrace, Boise, Idaho 83706.

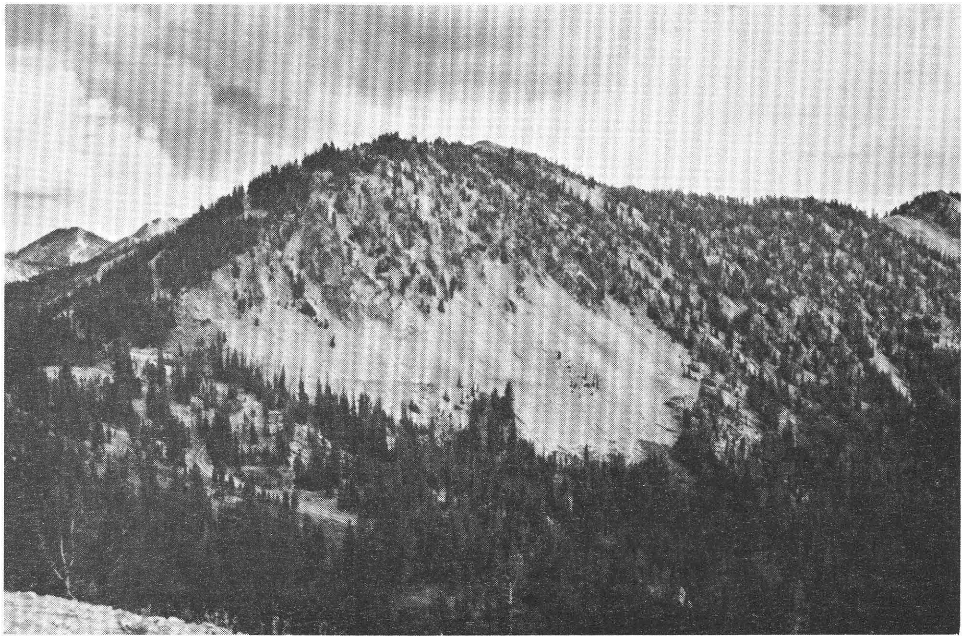

Figure 2. Trace of the Elk Summit fault in 1991. View from the ridge 0.8 km south of the talus apron. Elk Summit shows as a white patch of widened road near the left edge of the photograph.

The distant view of the train of dark blocks suggests that the train is separated into two segments, the shorter eastern one offset less than 20 m upslope from the longer western one. The offset, hardly noticeable to an observer on the talus apron, shows plainly on some pairs of 1:20,000-scale aerial photographs viewed stereoscopically (Richard B. Taylor, U.S. Geological Survey, oral commun., October 1992). The offset might be attributed to actual left-lateral offset along a northeast-striking line (a fault trace?) that Taylor saw distinctly on the photographs, or it might be attributed to independent development of the eastern segment of the dark train. In the present study, we treat the dark train and the narrow bench that accompanies it as features that for practical purposes mark a single fault.

The now unexposed fault can be detected by measurement of the local electromagnetic field. Four H-mode very low frequency (VLF) traverses along our lichen transects (described later) were run by means of a standard resistivity device, the Geonics EM–16, tuned to the Lualualei, Hawaii, radio transmitter, frequency 23.4 kHz. The measured inclinations (fig. 3) show no crossovers indicative of a strong conductor, but the contoured Fraser-filtered inclinations (fig. 4) show trends of low positive values that indicate a weak conductor beneath the fault bench or 5–15 m south of it. Higher electrical conductivity may result from increased pore water in the fault zone. The low positive values coincide with or are parallel to the fault bench; they are not parallel to the topographic contours sketched in figure 5. Better distance control for the VLF traverses gives an east strike for the fault trace, instead of the east-southeast strike sketched in figure 5, in which the relative positions of topographic contours and fault bench were approximated from elevations obtained using a pocket altimeter. The thickness of talus on the apron cannot be reliably estimated from the H-mode data, and the interpretation of conductors(?) north of the fault bench is uncertain, owing to the wide spacing of the VLF traverses. For the pros and cons of applying the simple numerical technique of date filtering introduced by Fraser (1969), see McNeill and Labson (1991, p. 614).

Curiosity about a fault that looked as if it had cut a talus apron "only yesterday" led us to try dating the Elk Summit fault by lichenometry. The fault is minuscule in comparison with other faults that are present within a few kilometers of the summit. Many of these faults strike north, parallel to or within the Eocene Profile–Smith Creek dike swarm (Leonard and others, 1968, p. C4–C5; Leonard and Marvin, 1982, fig. 1, table 1), a cross section of which is exposed on the ridge north of the talus apron. Talus from the dikes and the intervening screens of variably granulated, mylonitized, and granoblastic granite of the Idaho batholith forms the apron, whose largest dimensions are about 1,000 by 250 m. The blocks of the apron are mostly decimeters to 1–2 m in diameter, equant to slabby, without brownish, iron-stained, centimeter- to decimeter-size fragments of the sort found on parts of the fault bench and just downslope from it. The western half of the apron is devoid of trees and shrubs. We confined our lichen study to this area.

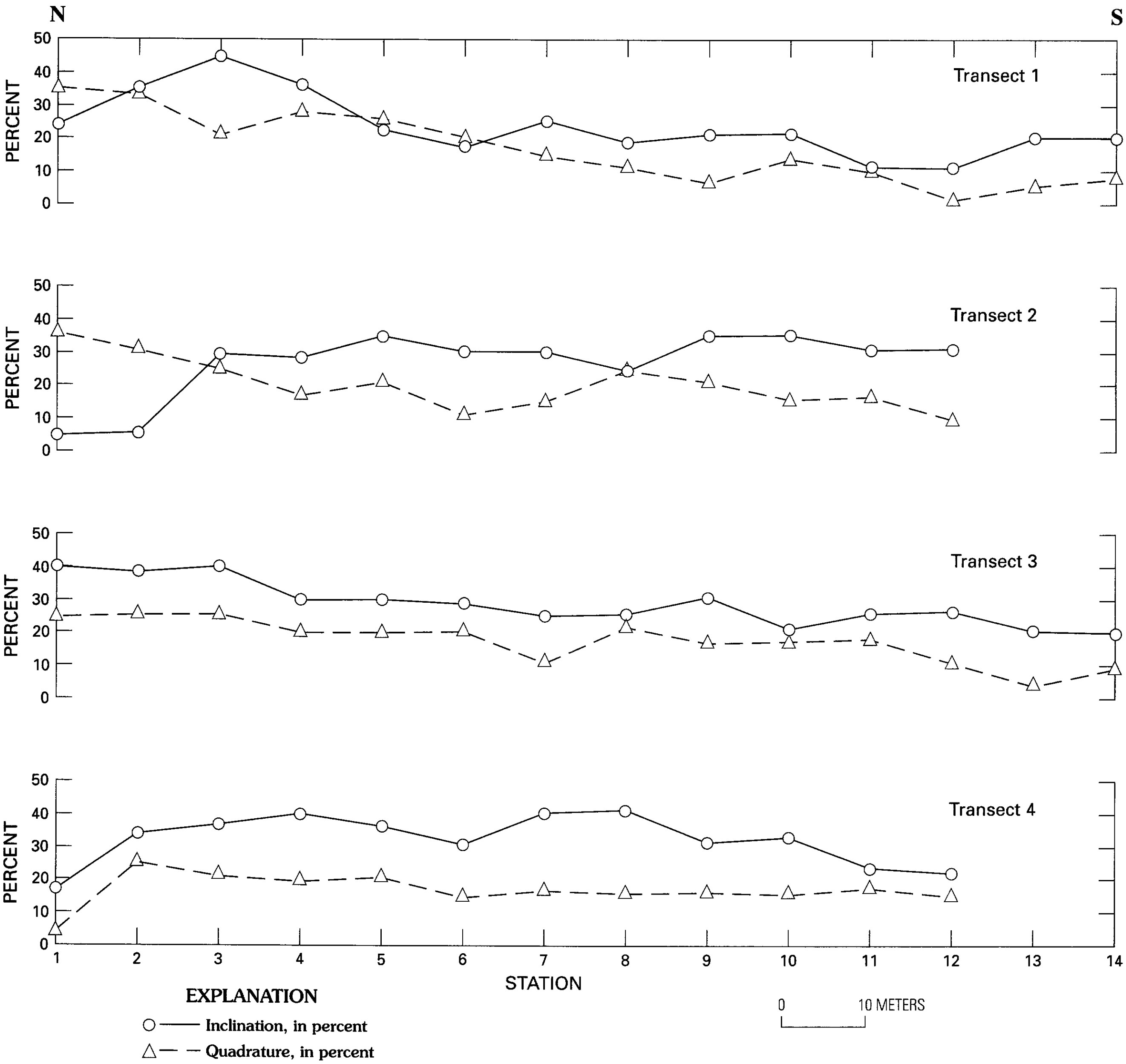

Figure 3. H-mode very low frequency (VLF) profiles, Elk Summit talus apron. Locations of transects are shown in figures 4 and 5. Inclination is that of the polarization ellipse of the electromagnetic field. Quadrature is a measure of the phase lag between the primary and secondary magnetic fields.

LICHENOMETRY AT ELK SUMMIT

Lichenometry—the measurement of the size of a lichen thallus in order to estimate the growth rate or age of the lichen—has been widely used to date Quaternary geomorphic features in North America and Europe. When lichenometry is applied to the dating of geomorphic features, it is customary to establish a suitable reference base by measuring the size of lichens on nearby, historically dated features such as cemetery monuments and buildings. The lichen commonly measured is *Rhizocarpon geographicum* sensu lato, a slow-growing, long-lasting areolate yellow lichen that has not always been discriminated from the rest of the *Rhizocarpon* subgenus. The Rhizocarpon used in our study has the characteristics given for *Rhizocarpon geographicum* (L.) DC. (Poelt, 1988; Benedict, 1988).

We also used the dark-brown to black, areolate lichen *Lecidea atrobrunnea*, which is larger and more abundant

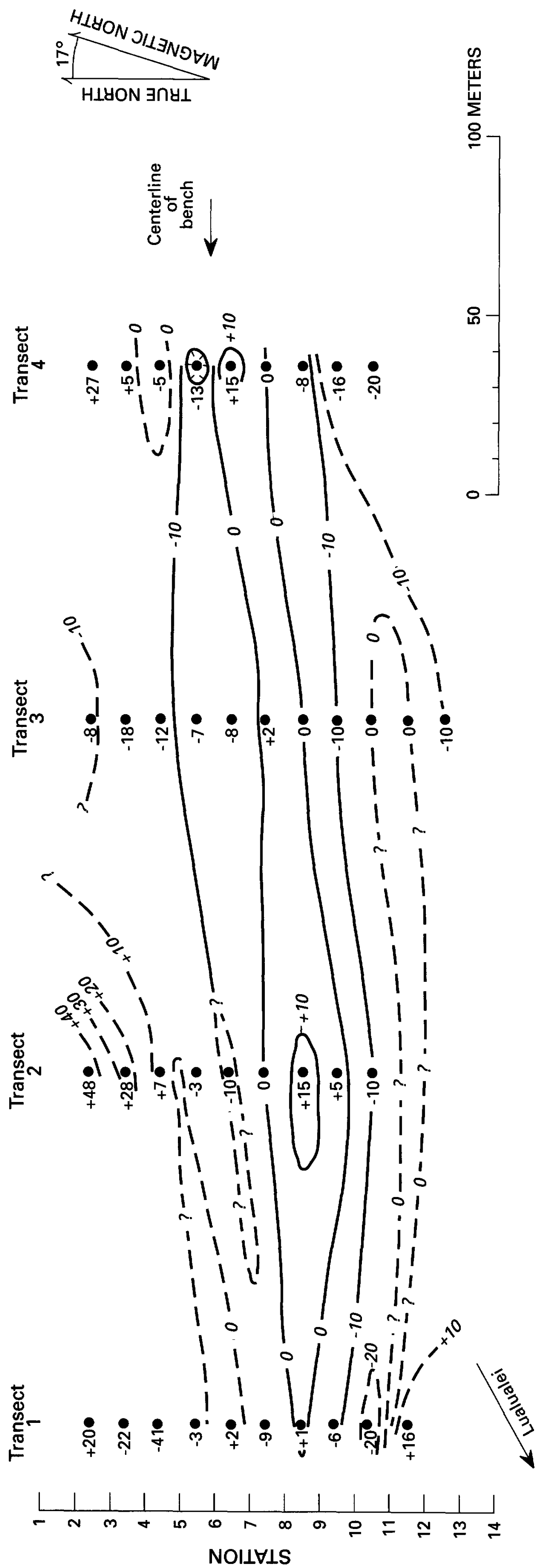

Figure 4 (left column). Fraser-filtered very low frequency (VLF) inclinations (in percent), Elk Summit talus apron.

than *Rhizocarpon geographicum* at Elk Summit. *Lecidea atrobrunnea* has occasionally been used for the dating of geomorphic features. Carrara and Andrews (1973) gave data on thallus size, percentage of cover, and growth rate of this lichen, among others, in the San Juan Mountains, Colorado.

Neither *Rhizocarpon geographicum* nor *Lecidea atrobrunnea* is ideally suited for dating geomorphic features less than a century old. Faster growing lichens such as *Xanthoria elegans*, used in the Canadian Rockies by Osborn and Taylor (1975), and *Pseudephebe minuscula*, used at Spitsbergen by Werner (1990), are more appropriate. At Elk Summit, *X. elegans* is rare, and *P. minuscula* has not been found.

Rhizocarpon geographicum and *Lecidea atrobrunnea* are present separately or together, with or without other lichens in small amount, on talus blocks of the Elk Summit apron. No one of the rock types—rhyolite, latite, quartz latite, and granite—seems to be favored as a host for the lichens. However, the percentage of cover given by the two major species varies widely from one talus block to another. Estimated roughly for the area transected, the percentage of cover is about 1–15 percent for *R. geographicum* and about 3–40 percent (commonly 15–20 percent) for *L. atrobrunnea* upslope from the fault bench, but less than 1 percent for both species on the fault bench. Percentage of lichen cover has been used by some workers to estimate the age of geomorphic features, but our semiquantitative data are not suitable for that purpose. Talus blocks from two obviously quite recent rockfalls are barren of lichens; our lichen transects did not cross these rockfalls.

Four 70-meter-long transects spaced 100 m apart were laid out across the fault trace in 1992 (fig. 5). A 6-meter-wide strip along each transect was scanned for large thalli of *Rhizocarpon geographicum* and *Lecidea atrobrunnea*, 8–15 of these were measured, and the 5 largest thalli of each species were accepted as indicators of maximum growth. The dimension measured is the diameter of the largest circle inscribable within a discrete thallus, one occurring in isolation or within a coalescing colony. The procedure for measurement is that recommended by Locke and others (1980). The lichen thalli that we measured showed no evidence of abrasion; the talus blocks were virtually in place before lichens grew on them. None of the blocks carrying measured lichens was a "bird rock," a perch on which chemical contamination from leached bird droppings might have promoted lichen growth.

The results for *Rhizocarpon geographicum* are given in table 1. At one standard deviation *s*, mean thallus size of *R. geographicum* does not differ significantly on upslope segments of the four transects (table 1). One thallus, diameter 54 mm on transect 4, might be taken as exceptionally large; if it is disregarded, thallus size on the upslope transect is 28–41

Table 1. Largest thalli of *Rhizocarpon geographicum*, Elk Summit talus apron, Big Creek area, Valley County, Idaho.

	n	Thallus diameter (millimeters)			
		Range	Mid-range	Median	$\bar{x}$±s
Transect 1					
Upslope segment	5	33–41	37	38	38.0±3.1
Fault bench	5	7–8	8	8	7.8±0.4
Downslope segment	5	32–45	38	35	37.2±6.0
Transect 2					
Upslope segment	5	36–45	40	38	39.4±3.4
Fault bench	5	6–10	8	7	7.4±1.7
Downslope segment	5	26–39	32	32	31.8±4.9
Transect 3					
Upslope segment	5	32–48	40	40	39.0±6.3
Fault bench	5	7–10	8	10	9.0±1.4
Downslope segment	5	24–38	31	31	29.8±5.6
Transect 4					
Upslope segment	5	32–54	43	34	38.6±9.4
Fault bench	5	7–9	8	8	7.8±0.8
Downslope segment	5	32–41	36	38	37.4±3.9
Combined data					
Upslope segment	20	32–54	43	38	38.8±5.6
Fault bench	20	6–10	8	8	8.0±1.3
Downslope segment	20	24–45	34	32, 33	34.1±3.8

Table 2. Largest thalli of *Lecidea atrobrunnea*, Elk Summit talus apron, Big Creek area, Valley County, Idaho.

	n	Thallus diameter (millimeters)			
		Range	Mid-range	Median	$\bar{x}$±s
Transect 1					
Upslope segment	5	59–82	70	62	65.4±9.5
Fault bench	3	5–33	19	7	15.0±15.6
Downslope segment	5	20–30	25	25	25.0±3.5
Transect 2					
Upslope segment	5	66–89	78	72	75.8±8.9
Fault bench	5	13–25	19	18	18.6±4.6
Downslope segment	5	60–73	67	62	66.0±6.4
Transect 3					
Upslope segment	5	68–92	80	72	76.8±9.6
Fault bench	5	12–26	19	12	14.8±5.2
Downslope segment	5	46–78	62	62	60.4±12.3
Transect 4					
Upslope segment	5	90–110	100	93	98.2±10.0
Fault bench	5	12–28	20	15	17.0±6.3
Downslope segment	5	95–110	102	100	102.0±7.6
Combined data					
Upslope segment	20	59–110	84	72, 80	79.0±15.0
Fault bench	18	5–33	19	15	16.5±7.2
Downslope segment	20	20–110	65	62	63.4±29.0

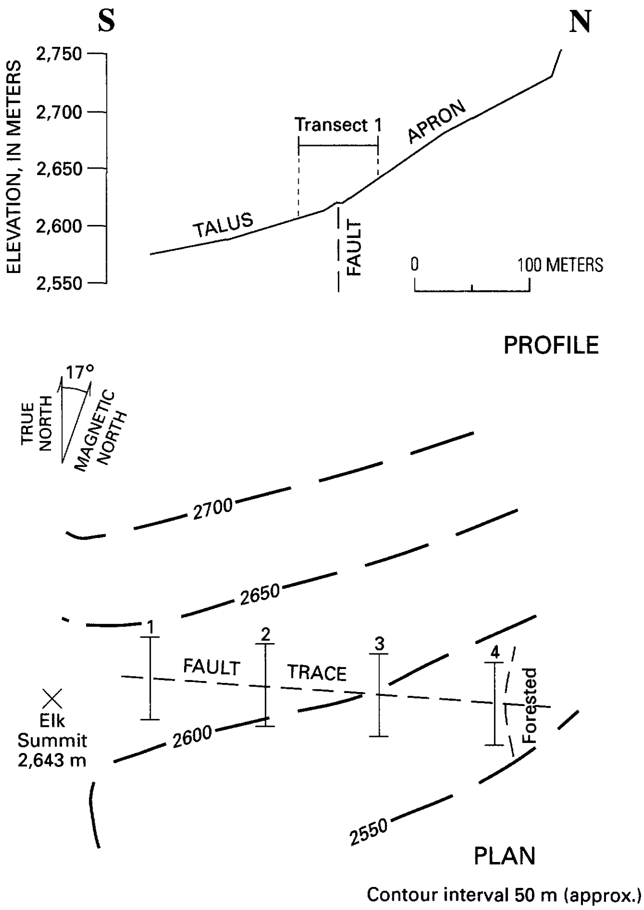

Figure 5. Transects for lichenometry, Elk Summit talus apron. The profile for transect 1 is representative.

mm, $\bar{x} \pm s$=33.4±4.8 mm. We doubt that the exception should be made. The combined data for thallus size on upslope segments of the four transects are accepted as reliable at $\bar{x} \pm s$=38.8±5.6 mm.

The maximum thallus size of *Rhizocarpon geographicum* on the fault bench is 8.0±1.3 mm, its coefficient of variation is the same as that for specimens measured upslope, and at three standard deviations there is no overlap in mean size. The lichen is not only sparser on the fault bench, it is much smaller—about one-fifth the size of thalli measured upslope.

Data for *Lecidea atrobrunnea* are given in table 2. This lichen is not only more abundant than *Rhizocarpon geographicum*, its thallus is about twice as large and, in proportion, shows greater variation. For *L. atrobrunnea*, the coefficient of variation is about 20–45 percent; for *R. geographicum*, it is about 10–15 percent. A few thalli of *L. atrobrunnea* approach or exceed 150 mm in diameter. These exceptionally large thalli have been excluded from consideration in table 2.

The combined data (table 2) for thallus size of *L. atrobrunnea* on the fault bench show a range from 5 to 33 mm. Within this range, 60 percent of the thalli are 12–18 mm in diameter. We later refer to this range as the common range. It has, for n=11 thalli, a midrange of 15, a median of 14, and $\bar{x} \pm s$=14.0±2.0 mm. The common range assumes some importance when we compare the data from Elk Summit with those obtained from cemetery stones of the region.

Owing to steepness of slope, the upslope, fault bench, and downslope segments of the transects may not yield equally reliable measurements of lichen size. Talus blocks upslope from the fault bench present no problem because the blocks constitute a single population. However, some slight, local contamination of the on-bench assemblage by talus blocks displaced from above, and of the below-bench assemblage by blocks displaced from the bench, is inevitable. Block size, position, and degree of weathering are aids in classifying lichen-bearing blocks as essentially in place or transported, but the application of these criteria is judgmental.

Paul Carrara (written commun., 1993) presented the hypothesis that two populations of lichens, differing in age, are present on the fault bench. He advanced this hypothesis as support for the two episodes of faulting discussed in the Conclusion of our report. However, the low coefficient of variation (12 percent) of the maximum thallus size of *Rhizocarpon geographicum* speaks against the hypothesis. For *Lecidea atrobrunnea*, the case is not so clear; the corresponding coefficient of variation is large (44 percent). By measuring at least 100 large thalli of this lichen one might find evidence of more than one size-age population, but we doubt that so many representatives are available for measurement. Thus, the Carrara hypothesis remains to be tested.

Other lichen species from the Elk Summit talus apron are given in table 3. The nomenclature follows that of Egan

Table 3. Lichen species at Elk Summit, Big Creek area, Valley County, Idaho, and their relative abundance.

Lichen species	Abundance
Acarospora chlorophana	Rare.
Acarospora sp. (dark)	Common.
Aspicilia cinerea	Common.
Aspicilia gibbosa	Common.
Aspicilia sp.	Abundant.
Candelariella vitellina	Rare.
Lecanora sp.	Rare.
Lecidea atrobrunnea	Abundant.
Lecidea tessellata	Common.
Rhizocarpon geographicum	Common.
Rhizoplaca melanophthalma	Rare.
Tremolecia atrata	Rare.
Umbilicaria hyperborea	Rare.
Umbilicaria krascheninnikovii	Rare.
Xanthoparmelia sp.	Rare.
Xanthoria elegans	Rare.

(1987). Vouchers of these lichens are in the Snake River Plains Herbarium at Boise State University, Boise, Idaho.

LICHENOMETRY IN CEMETERIES

Before we interpret the data for thallus size on the Elk Summit talus apron, we present for comparison data on *Rhizocarpon geographicum* and *Lecidea atrobrunnea* from headstones in cemeteries of the region. Unfortunately, there are no dated, lichen-bearing features near Elk Summit. The three graves found at Big Creek (fig. 1) have concrete or metal markers. The cemeteries at Warren and Yellow Pine have few graves, and few of these have stone markers. Cemeteries in the McCall area, 60 km southwest of Elk Summit, have some selection of stones useful to the lichenometrist. Even so, these cemeteries are not favorably situated, in elevation, climate, or stone type, to provide the extensive data base that we hoped to get for *Rhizocarpon geographicum* and *Lecidea atrobrunnea.*

Cemetery elevations and locations are given in the notes accompanying table 6 (later). The cemetery at Warren, elevation 1,850 m, is the highest; it is nearly 800 m lower than Elk Summit, elevation 2,643 m. The other cemeteries are 1,100–1,400 m lower than Elk Summit. The scarcity of *Rhizocarpon geographicum* in cemeteries of the McCall area, the small size of its thalli, and the absence of this lichen from stones in the cemetery at Meadows suggest that the lower limit of elevation for *R. geographicum* is between 1,200 and 1,500 m under the climatic conditions prevailing here, at lat 45° N., during the last 100 years.

Climate at the cemeteries is broadly similar, in spite of differences in elevation (table 4). The montane climate at Warren and Big Creek is similar to the subalpine climate of Elk Summit, the high pass between those settlements, but the differences may be considerable. At Elk Summit, the mid-winter temperature may not be much lower than at Big Creek, but snow accumulates earlier in the fall (late August to late September) and lasts about a month longer in the spring (late June to late July). Summer days are about 5°C cooler, and many of them are windy. Artificial watering of the McCall, Finnish, and Meadows Valley cemeteries keeps them damper than the Elk Summit talus apron and, with some shade, promotes the growth of foliose lichens. *Rhizocarpon geographicum* and *Lecidea atrobrunnea* on the cemetery stones are restricted to the cooler, less sunny north and east sides, as are most of the foliose lichens. One crustose lichen, *Aspicilia calcarea*, grows profusely on the tops and west sides of the stones.

Much stone used in the cemeteries after 1920 is chemically comparable to talus rock at Elk Summit: various red and gray granites, red granite gneiss, dark-gray hornblende quartz diorite and hornblende-biotite quartz diorite, and minor syenite and anorthosite in the cemeteries; rhyolite, latite, quartz latite, and deformed granite at Elk Summit. Texturally, however, there are differences: the cemetery stones are mostly medium to coarse grained; the talus rock is mostly fine grained, even where phenocryst bearing. The unfinished surfaces of cemetery stones less than 50–60 years old are virtually unweathered; the surfaces of talus blocks range from smooth to slightly rough, all blocks except those from very recent rockfalls show at least some weathering (usually as bleaching, or as limonitic staining), and thin weathering rinds have developed on some. *Rhizocarpon geographicum* and *Lecidea atrobrunnea* do not grow on the sanded or polished surfaces of cemetery stones; some other lichen species do.

The record for cemetery stones suitable for our lichenometry is a short one, about 70 years. Nearly all the stones bearing death dates earlier than the mid-1920's are gray or white marble, commonly lichen bearing but devoid of *Rhizocarpon geographicum* and *Lecidea atrobrunnea.* Considered as a whole, the cemeteries have no more than 10 or 15 percent of these old marble stones.

Another problem in the use of cemetery stones for lichenometry is also cultural. Most of the local graves are

Table 4. Climatic data for montane communities near Elk Summit, Big Creek area, Valley County, Idaho.
[Data supplied by Idaho State Climatologist, written commun., September 1992]

Community	Elevation (meters)	Annual precipitation	Mean January temp.	Mean July temp.	Years of record	Length of record
Warren	1,800	67.4±15.8	–6.9±1.2	13.6±0.5	1962–1991	30
Big Creek	1,753	72.9±14.9	–6.8±1.6	14.7±0.4	1952–1967	16
Yellow Pine	1,451	66.1±17.1	–6.5±1.3	15.4±0.5	1971–1987 1989–1991	20
McCall	1,527	68.4±12.4	–6.6±1.7	16.9±0.5	1930–1955 1957–1991	61
New Meadows[1]	1,213	61.3±11.9	–7.3±2.0	17.3±0.7	1962–1991	30

[1]New Meadows is 3 km west of Meadows.

Table 5. Frequency of *Rhizocarpon geographicum* and *Lecidea atrobrunnea* on cemetery stones.
[See table 6 for elevation and location of cemeteries]

	Number of stones bearing measurable thalli	Total number of stones examined	Percent bearing the lichen
	Rhizocarpon geographicum		
Warren	4	8	50
Yellow Pine	1	5	20
McCall	12	380	3
Finnish	8	~250	3
Spink	3	62	5
Meadows	0	462	0
	Lecidea atrobrunnea		
Warren	0	8	0
Yellow Pine	0	5	0
McCall	20	380	5
Finnish	27	~250	11
Spink	4	62	6
Meadows	0	462	0

marked with headstones but no footstones for the individual graves in a plot; many headstones commemorate two members of a family and thus may bear two widely different death dates; and, judged from stone type and lettering, some stones were set years after the death date marked on them. Actual setting dates were sought but not found.

Rhizocarpon geographicum is sparse and small on stones in the cemeteries. *Lecidea atrobrunnea* is roughly twice as abundant and twice as large. Most prevalent is an areolate lichen that looks somewhat like *L. atrobrunnea* in form; it is *Aspicilia calcarea*, which is gray and prefers a calcareous substrate. We have not recognized *A. calcarea* at Elk Summit; there, all substrates are noncalcareous.

The frequency of *Rhizocarpon geographicum* and *Lecidea atrobrunnea* on cemetery stones, expressed as percent of stones bearing measurable thalli, is shown in table 5. (The frequency so expressed is not equivalent to percent of lichen cover, which—too low to be reliably measured—may be of the order of 1×10^{-2}–1×10^{-5} percent.) The marked decrease in the frequency of *R. geographicum* from Warren to the McCall area suggests that Warren and Yellow Pine, closer to Elk Summit, are more favorable for the growth of this lichen. Nevertheless, the growth rates calculated for the Warren samples differ but little from the rates calculated for samples from the McCall and Finnish cemeteries.

The scarcity of *Rhizocarpon geographicum* and *Lecidea atrobrunnea* on cemetery stones severely limits the collection of data on thallus size. Data for these lichens are given in tables 6 and 7. Some stones carry one of the two species but not the other; some stones carry both species. The absence of *R. geographicum* from stones bearing death dates later than 1959 or 1963 (?) suggests that this lichen may take about 30 years to become established and grow to detectable size in the cemeteries. Small thalli of *L. atrobrunnea* are difficult to identify and for that reason were not sought.

Other lichens in the cemeteries are listed in table 8.

DATING THE ELK SUMMIT FAULT BY LICHENOMETRY

Our first trial is a direct and simple one, that of matching the size of the largest thalli of *Rhizocarpon geographicum* on the fault bench and in the cemeteries. On the fault bench, it is 6–10 mm, $\bar{x}\pm s=8.0\pm1.3$, $n=20$ (table 1, combined data). The closest size match, given by the 1932 stone at Warren, is 7–10 mm, $\bar{x}\pm s=8.0\pm1.4$, $n=5$ (table 6). This would give a single date for the fault, 1932.

Matching for *Lecidea atrobrunnea* is not so simple because the size of the largest thalli on the fault bench has a wide range, 5–33 mm, $\bar{x}\pm s=16.5\pm7.2$, $n=18$ (table 2, combined data). The common range, however, is 12–18 mm, $\bar{x}\pm s=14.0\pm2.0$, $n=11$. We think it appropriate to seek a match based on the common range. At the cemeteries, a close match is 9–21 mm, median 14 (table 7, entry B), death dates on stones 1919–1951. We now have an estimate of the range of possible dates for the fault.

Growth-rate curves for *Rhizocarpon geographicum* and *Lecidea atrobrunnea* from the cemeteries cannot be constructed, owing to the scattering of data points given by highly discrepant dual death dates incised on many stones. Therefore, for *R. geographicum* we use growth rates from the few stones that have singular death dates or a pair not widely different. Growth rates so based are 0.12 or 0.13 mm per year (table 6, entries A and B). If we accept the value 0.13±0.04 because it has a wider range, and if we also take into account the standard deviation of the mean size of *R. geographicum* on the fault bench, the dates estimated for the fault range from 1913 to 1936, mean 1925±7.

Growth rates for *Lecidea atrobrunnea* in the cemeteries have a wide range, even if we eliminate from consideration the rates based on thalli smaller or larger than those in the range common for Elk Summit. The mean growth rate for thalli above the common range is not significantly different, at one standard deviation, from the mean growth rate for thalli in the common range (table 7, entries B and C); either value is usable. We shall use 0.28±0.06 mm per year, the average obtained by weighting the B and C values according to the number of stones bearing the lichen. Taking into account the standard deviation in thallus size of *L. atrobrunnea* on the Elk Summit fault bench, as well as the standard deviation of the growth rate, we estimate the dates for the fault to be 1919 to 1957, mean 1940±12.

Table 6. *Rhizocarpon geographicum* on cemetery stones.

Cemetery	Death dates on headstones	Number of stones bearing the lichen	Number of measured largest thalli per stone	Thallus diameter (millimeters)				Growth rate (millimeters per year)
				Range	Midrange	Median	$\bar{x}$±s	
Warren	1920–1936	4	2–5	1.5–13	7	5, 7	--	--
	1920	1	5	3–13	8	5	6.2±3.9	0.12
	1932	1	5	7–10	8	7	8.0±1.4	0.13
Yellow Pine	1938	1	5	5–8	6	5	5.8±1.6	0.11
McCall	1923–1959	12	1–5	2–14	8	6, 7	--	--
	1934, 1946	1	5	7–14	10	8	9.6±3.2	0.17, 0.21
	1943	1	3	4–6	5	5	5.0±1.0	0.10
Finnish	1919–1947	8	1–2	2–6	4	3	--	--
Spink	1918–1942	3	1	2–6	4	--	--	--
Meadows	--	0	--	--	--	--	--	--

Growth rate summary (in millimeters per year)

	n	Range	Midrange	Median	x±s
A. Values from all individual stones (in calculating x, death dates averaged for stone having two dates)	5	0.10–0.21	0.16	0.13	0.13±0.04
B. Values from individual stones having single death date	4	0.10–0.13	0.12	0.11, 0.12	0.12±0.01

Description of cemeteries

Warren Cemetery, Warren. Elevation 1,850 m, 150 m northeast of road (main street) and 45 m above it. Warren quadrangle. Moderate shade. Death dates on headstones 1900–1988; oldest death date on wooden markers 1870.

Pioneer Cemetery, Yellow Pine. Elevation 1,437 m, east bank of Johnson Creek, 1.0 km south-southwest of Yellow Pine Post Office. Yellow Pine quadrangle. No shade. Death dates on grave markers not recorded in field notes; 5 headstones, 17 markers of concrete or metal.

McCall Cemetery, McCall. Elevation 1,539 m, Mission Street, 1.0 km south of East Lake Street (main street), or 0.6 km north of airport. McCall quadrangle. Much shade. Death dates on headstones 1907–1992.

Finnish Memorial Cemetery. Elevation 1,524 m, Farm to Market Road, 9.8 km north of Roseberry, a hamlet 30 km south-southeast of McCall. Lake Fork quadrangle. Little shade. Death dates on headstones 1904–1992.

John Spink Memorial Cemetery. Elevation 1,500 m, Farm to Market Road, 7.4 km north of Roseberry. Lake Fork quadrangle. Little shade. Death dates on headstones 1900–1991.

Meadows Valley Cemetery, Meadows. Elevation 1,210 m, just east of Cemetery Road, 2.2 km north of Highway 55, Meadows quadrangle. Death dates on headstones 1886–1991.

So far, we have adhered as closely as possible to the currently recommended practice in lichenometry: base estimates of age on the mean diameter of the five largest thalli. Formerly, age estimates were based on the size of the single largest thallus. It is instructive to revert to the older practice to see what it gives for the age of the fault when we use *Rhizocarpon geographicum*. The largest thallus on talus of the fault bench has a diameter of 10 mm (table 1, combined data). The largest thallus in the cemeteries has a diameter of 14 mm; it is on a stone bearing two death dates, and the calculated growth rates are 0.24 and 0.30 mm per year (table 6, McCall cemetery, dates 1934 and 1946). Obviously one of the growth rates is specious, but we do not know which. Therefore, the estimated date of the fault is either 1950 or 1959. Both dates are credible, the latter more so when we recall that the fault scarp looked fresh in the mid-1960's.

Lecidea atrobrunnea, treated in the same way, gives a much older date. The largest thallus on talus of the fault bench has a diameter of 33 mm (table 2, combined data). The largest thallus in the cemeteries has a diameter of 26 mm (table 7, entry C). This thallus is on the stone that also bears the largest Rhizocarpon thallus, the death date on the stone is

Table 7. *Lecidea atrobrunnea* on cemetery stones.

Cemetery	Death dates on headstones	Number of stones bearing the lichen	Number of measured largest thalli per stone	Thallus diameter (millimeters) Range	Midrange	Median	Growth rate (millimeters per year)
Warren	--	0	--	--	--	--	--
Yellow Pine	--	0	--	--	--	--	--
Meadows	--	0	--	--	--	--	--
McCall, Finnish, and Spink[1]							
A. Thallus diameter <9–21 mm range	1916–1964(?)[2]	11	3–5	<5–11	≤8	8	0.10–0.20 0.14±0.03
B. Thallus diameter 9–21 mm range[3]	1919–1951	11	3–5	9–21	15	14	0.19–0.36 0.27±0.06
C. Thallus diameter >9–21 mm range	1916–1935	6	3–5	16–26	20	20, 22	0.24–0.41 0.31±0.06

[1]Combined record. No statistically significant difference in growth rates in the three cemeteries.
[2]Death date on one stone is 1947, but setting date is taken as 1964(?), the death date on the adjacent identical stone of another family member.
[3]Close to the common range, 12–18 mm, for thalli on the fault trace, Elk Summit talus apron. To get a representative number of values from cemetery stones, the range is extended to 9–21 mm. Only two stones showing single death dates have three or more thalli in the 12–18-mm range. Growth rates are 0.30 and 0.36 mm per year, respectively, on stones showing 1946 and 1951 dates.

Table 8. Lichen species on the cemetery stones of the McCall and Finnish cemeteries and their relative abundance.

Lichen species	McCall	Finnish
Acarospora chlorophana	Absent	Rare.
Acarospora sp. (brown)	Rare	Rare.
Aspicilia calcarea	Common	Common.
Bacidia sp.	Common	Common.
Caloplaca holocarpa	Rare	Rare.
Candelariella rosulans	Common	Common.
Lecanora muralis	Common	Abundant.
Lecanora sp.	Rare	Rare.
Lecidea atrobrunnea	Common	Common.
Melanelia subelegantula	Common	Common.
Physcia caesia	Rare	Rare.
Physcia sp.	Rare	Rare.
Rhizocarpon geographicum	Common	Common.
Rhizoplaca chrysoleuca	Absent	Common.
Rhizoplaca melanophthalma	Rare	Common.
Staurothele clopimoides	Absent	Common.
Toninia caeruleonigricans	Absent	Rare.
Umbilicaria hyperborea	Rare	Common.
Umbilicaria krascheninnikovii	Common	Common.
Umbilicaria virginis	Absent	Common.
Xanthoria elegans	Absent	Common.
Xanthoria fallax	Rare	Abundant.
Xanthoria polycarpa	Rare	Common.

1935, and the calculated growth rate of *L. atrobrunnea* is 0.46 mm per year. From this growth rate, the estimated date of the fault is 1920.

In summary, the comparative lichenometry of *Rhizocarpon geographicum* and *Lecidea atrobrunnea* gives a range of dates, 1913 to 1959, for the fault that cuts the Elk Summit talus apron. The precision of estimate for the limiting dates is not high. Inasmuch as the range is 1913–1919 for the earliest dates and 1950–1959 for the latest, it is reasonable to suppose that some few years might be subtracted from 1913 and added to 1959, placing the earliest date of faulting in the first decade of the century and the latest in the 1960's. Lichenometry and geologic observation are in agreement: the fault is young, formed sometime after settlements were established at Warren and Big Creek.

Comparative lichenometry also indicates that talus upslope from the fault trace (excluding talus from recent rockfalls) is about 250–300 years old. This unexpectedly ancient age points to considerable stability of the upper surface of the main part of the talus apron.

DATING THE ELK SUMMIT FAULT BY AERIAL PHOTOGRAPHY

The range of dates given by lichenometry can be narrowed by examining a series of aerial photographs taken between 1946 and 1974. The scale of the photographs ranges from 1:20,000 to 1:60,000. Contact film negatives were required for resolution of critical features on the 1946 and 1954 photographs; positive prints were adequate for photographs taken subsequently. Photographs taken on September 29, 1946, show the talus apron covered with snow. Nevertheless, a poorly defined, east-trending linear feature is visible on the west half of the talus apron, and a better defined linear feature is visible at the east edge of the apron. The features are collinear, though separated by a gap. A faint northeast-trending zone can be projected into the gap, but the zone does not appear to offset the east-trending features. Photographs taken July 31, 1954, also show snow on the talus apron. A barely visible break in slope defines the western linear feature, the eastern one is not evident, and the northeast-trending zone is obscure. Photographs taken on August 24, 1964, clearly show straight, dark lines marking the segmented fault trace, though the talus apron has some snow cover. The offset of the segments, estimated perpendicular to their length, is about twice the 4-meter width of the nearby forest road, or about 10 m. (Compare figure 2.) Photographs taken on August 20, 1969, still show straight, dark lines marking the segmented fault trace. Photographs taken on September 2, 1974, also show the dark lines, but the lines are slightly crinkly or wavy, distorted a little by local movement of talus. Richard B. Taylor (oral commun., October and December 1992) reported the foregoing observations after examining the whole series of photographs stereoscopically.

The evidence from the series of aerial photographs indicates that the Elk Summit fault had some surface expression as early as 1946, little changed in 1954 but conspicuous by 1964. The major change in surface expression is thus narrowed to the interval 1954–1964.

SEISMIC EFFECTS

Most young faults that have surface expression have resulted from earthquakes or are known to be associated with them. Is the Elk Summit fault earthquake related? The seismicity map of Idaho (Stover and others, 1991) shows no epicenters close to Elk Summit. Only one earthquake centered within 100 km of Elk Summit is reported to have had an intensity as high as VII on the modified Mercalli scale. That moderately strong earthquake, of magnitude 6.1 mb, occurred in 1944 in the Sheep Mountain area 60 km southeast of Elk Summit (Stover and others, 1991). We have no information on effects that might have been felt in the Big Creek–Yellow Pine area.

Major earthquakes commonly have effects that extend far from their epicenters. One such earthquake, felt at Big Creek and near Yellow Pine, was the August 18, 1959, earthquake at Hebgen Lake, Montana. The magnitude of the principal shock was 7.1 mb (Reagor and others, 1985). The effects of the earthquake were felt over an area of $\sim 6\times10^5$ mi^2 (Murphy and Brazee, 1964, p. 15), equivalent to $\sim 1.6\times10^6$ km^2. The seismologists' August 18 date is referred to Coordinated Universal Time (06:37:15 UCT); the equivalent in Mountain Standard Time is 11:37 p.m., August 17.

At Big Creek, Robin McRae was sleeping in a two-story frame house set on concrete blocks on Quaternary deposits of the valley floor. He awoke about 2:30 a.m. when "an earthquake almost tore the cabin apart. He thought it was a bear trying to get into the house. [McRae] thought that it was the same earthquake that struck in Montana on the Madison river" (James Collord, written commun., August 14, 1992). The discrepancy in time between the 11:37 p.m. shock and McRae's sensing of it at 2:30 the next morning may be significant, but we are inclined to discount the discrepancy.

Also at Big Creek, the Wiles cabin close to the McRae house was shaken. "The quake of 1959 shook my cabin * * * rattled stovepipe, windows etc. It also cut the flow of a spring on Mountal [Monumental] Cr. to about ½ what it was" (Wilbur Wiles, written commun., September 22, 1992). The spring is at the mouth of an unnamed creek 0.3 km northeast of Diamond Creek, 22 km east of Elk Summit. The estimated intensity of the earthquake's effect at the spring is VIII (modified Mercalli scale), in contrast to VI at Big Creek.

At Chamberlain Basin, 30 km northeast of Elk Summit, Earl Dodds was awakened during the night when his wood-floored frame tent was severely shaken twice within a short time span. He thought that a bear was the shaker, but his searches for the bear showed no evidence that one had been present (Earl F. Dodds, former U.S. Forest Service District Ranger, Big Creek district, oral commun., October 16, 1992).

At Meadow Creek Lookout, a one-story frame building set on the bedrock of Meadow Ridge 13.3 km southeast of Yellow Pine, the Forest Service observer was awakened when canned goods stored on the rafters rained down upon him. Quite distraught, he burst into Leonard's camp 2 km southeast of the lookout early next morning to report the accident. Leonard, his field assistant, and his packer had slept peacefully on the ground on their air mattresses; no one felt the shock, and it did not "spook" the horses and mules grazing nearby. Everyone agreed that the accident at the lookout was caused by an earthquake, but no one knew until a newspaper became available some days later that the epicenter of the earthquake was at Hebgen Lake, 320 km east of the lookout.

At the Cox Ranch, 14.4 km south of Yellow Pine, Emma Cox (written commun., November 4, 1992) "felt [the earthquake while] standing in the kitchen and some of the cabinet doors came open. Later we noticed the cement on the fireplace chimney on the outside had a crack clear through that had not been there before."

These examples of earthquake effects felt or later observed near Elk Summit indicate the wide-ranging effect of the Hebgen Lake earthquake. Was the effect great enough to develop a fault across the Elk Summit talus apron? No one can say, because an understanding of the intensity of earthquake effects that occur far distant from an earthquake focus is only now developing.

Was there, at the time of the Hebgen Lake earthquake, a discrete earthquake centered much closer to Elk Summit—an earthquake not detected instrumentally because its signal was irresolvable from those given by the Hebgen Lake shocks? The question arises, but it is unanswerable.

An initially puzzling feature of the size distribution of fragments on the talus apron is consistent with an earthquake origin for the fault, whatever its date. This feature is the brownish, iron-stained fines that are restricted to the fault bench and a narrow zone downslope from it. The fines, mostly of centimeter size, are very likely the analog of the sand and gravel erupted as sand boils or sand spouts along earthquake-induced faults in unconsolidated sediments. (For a description of the sand spouts caused by the Hebgen Lake earthquake, see Swenson, 1964, p. 162–163.) On the Elk Summit talus apron, fines that had been eluviated from the surface and deposited at shallow depth were forced upward when snowmelt stored in the talus was squeezed out along the fault during local compaction of the talus blocks. The finest material so erupted has been dispersed, as it has been from sand spouts in soft sediments, but centimeter-size fragments remain to give the material on the fault bench its anomalous, iron-stained, screelike character.

CONCLUSION

The lichenometry of *Rhizocarpon geographicum* and *Lecidea atrobrunnea* gives a wide range of 20th century dates, including 1959, for the Elk Summit fault. The evidence from aerial photographs narrows the range of dates for conspicuous surface expression of the fault to 1954–1964. A 1959 date is consistent with the fresh appearance of the fault scarp in the mid-1960's, and with the obliteration of the scarp sometime between the 1960's and 1991. If the scarp degenerated to an inconspicuous bench in a period of 25 or 30 years, it is unlikely that the scarp persisted for 25 or 30 years before the 1960's. We believe that the Elk Summit fault dates from 1959, the year of the Hebgen Lake, Montana, earthquake. The effects of that far-distant earthquake were felt strongly or observed later within 9–30 km of Elk Summit. This fact suggests that the Elk Summit fault resulted from the Hebgen Lake earthquake or from some attendant shock, not detected instrumentally, that may have occurred closer to Elk Summit. The earthquake may have served only as a trigger for surface faulting related to a bedrock fault of far greater age.

We readily admit that neither a 1959 date for the fault nor an earthquake origin for it can be proved by our study, provocative as the facts and inferences may be. We also admit that we are puzzled by the poorly defined linear feature visible on 1946 air photographs of the talus apron. The feature suggests that an episode of surface faulting may have occurred sometime between the first and fifth decades of this century. Judged from lichenometry, an earlier date is unlikely. It is tempting to relate this enigmatic episode of faulting to the 1944 Sheep Mountain earthquake, but to do so is conjectural. We set out to date the fault that had conspicuous surface expression during the 1960's; that date is most likely 1959.

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