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Measurement of ridge-spreading movements (Sackungen) at Bald Eagle Mountain, Lake County, Colorado, 1975-1989

by

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INTRODUCTION

Investigations in many of the mountainous parts of the world during the last 25 years have shown that large mountain masses have undergone spreading movements under their own weight. The movements are inferred to be nearly horizontal near the base and both lateral and vertical near the crest of the mass. These displacements commonly produce distinctive geomorphic features such as upward-facing scarps on the flanks of ridges and grabens along their crests. Spreading movements are most common in glaciated regions and may have begun when the retreat of ice from the valleys left adjacent slopes oversteepened and unsupported. The observed displacements are generally one to a few meters at each scarp, rarely some tens of meters, and the movements in most places appear to have been completed long ago. However, in some localities, closed depressions and holes unfilled with soil or vegetation indicate that slow movements may continue.

Geomorphic features that indicate gravitational spreading have been noted in several geologic settings. Where isolated masses of igneous rock lie on soft shale, as at some laccoliths of south-central Colorado, the overlying brittle crystalline rocks may spread on the underlying plastic shale. This is to be expected; but ridges composed entirely of homogeneous granitic rock also appear to have spread. In all instances that we have observed, the spreading mass of whatever composition is closely divided by well-developed sets of joints. Such is the condition of rock at Bald Eagle Mountain, a broad ridge of somewhat gneissic Precambrian granite extending northeastward from Mount Massive, one of the high peaks of the Sawatch Range of west-central Colorado (fig. 1).

The area of study 1½-2 miles southwest of the high point of Bald Eagle Mountain is shown in figure 2. A shallow graben between stations 1 and 4 follows part of the broad ridge crest, and several arcuate trenches and upward-facing scarps parallel the contours high on the northwest-facing slope between stations 1 and 3. These features were brought to our attention by R.B. Colton during his aerial photograph reconnaissance and compilation of landslides in this region of Colorado (Colton and others, 1975).

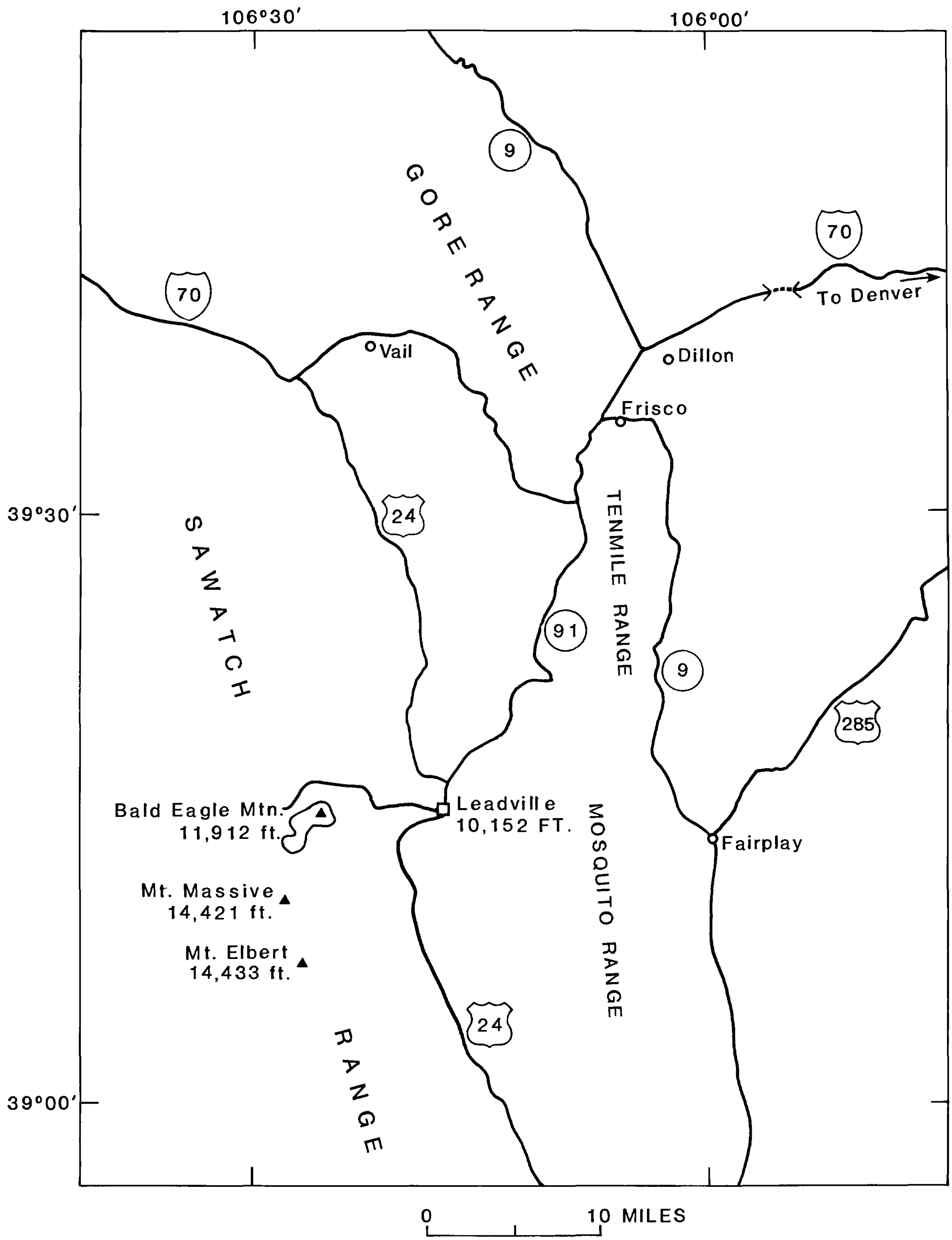


FIGURE 1.--Location of Bald Eagle Mountain in the Sawatch Range of Colorado.

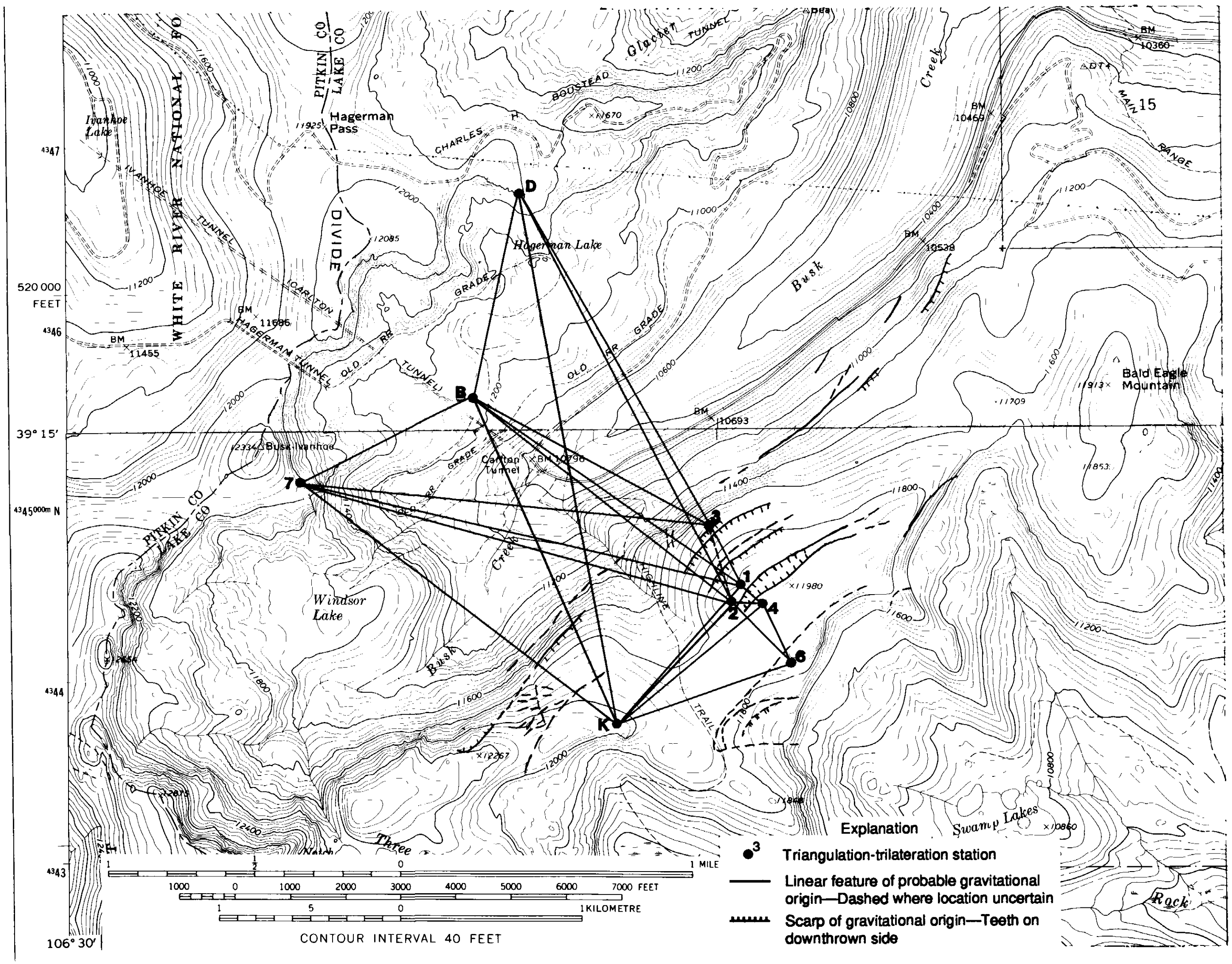


FIGURE 2.--Survey net at Bald Eagle Mountain and valley of Busk Creek, Lake County, Colorado. Base map is from the Homestake Reservoir, 1970, and Mount Massive, 1967, 1:24,000 topographic sheets, U.S. Geological Survey.

Geologic study of the gravitational spreading features at Bald Eagle Mountain and several nearby ridges began in 1975. The relation of these features to local topography and geologic structures is discussed in a recent paper (Varnes and others, 1989). At the beginning of our study, a few surveyed points were placed to determine if any movements were continuing. In succeeding years, more points have been added to the survey net, which now extends over about 2 km, and observations have been repeated at intervals of 2 to 5 years.

The Bald Eagle Mountain study area is one of moderate relief between elevations 3200 and 3660 m (10,500 and 12,000 ft). Access to the foot of the slope is by a hard-surface road from the city of Leadville, past Turquoise Lake, and by a gravel road up Busk Creek to the portal of the Carlton Tunnel. This unimproved road continues north and westward over Hagerman Pass on the Continental Divide and on to the town of Basalt. Access on foot toward those stations of the survey net that are on Bald Eagle Mountain is by a Forest Service trail that begins at the parking lot near the east portal of the Carlton Tunnel and zig-zags up the slope to the southeast. Under favorable weather conditions, all stations were approached also by helicopter close enough for transport of the surveying equipment on foot. After 1984, this was no longer possible as the east side of the valley of Busk Creek lies within the Mount Massive Wilderness Area and helicopter operations are prohibited.

Because the ability to continue combined trilateration-triangulation among all stations, as originally intended, has been lost, this report presents results of the measurements made so far and the methods used to obtain them.

METHOD OF OBSERVATION

Most observation points are 18-in., copper-clad steel stakes with flat heads marked with a center punch. These were driven either until heads were flush with the ground or to refusal. Station 1, in a place that might be subject to disturbance by passers-by, is a small screw glued in rock.

Movements of the observation points were expected to be small, if they existed at all. Therefore, measurements were made as accurately as possible, consistent with high-altitude working conditions and the time and funds available for personnel and helicopter support. Before 1989, combined triangulation and trilateration were used in which all distances and all horizontal angles were observed, either in triangles or in braced quadrilaterals. Slope distances were measured by electronic distance-measuring devices, and horizontal distances and elevation differences were computed from zenith angles.

Horizontal and vertical angles were observed with a Wild T-2 1-second theodolite. All horizontal angles were measured individually, not in a series, once in direct and once in inverted positions of the telescope, and repeated if necessary to obtain satisfactory agreement. Angles to complete a 360° circuit around a station were measured. Vertical angles were recorded at each pointing, thus providing four values to be averaged. Before 1989, targets were standard black-and-white Wild or Lietz models. In some instances, horizontal angles were measured to the center of prism reflectors and the vertical angles corrected for offset position of the prism face. In 1989, horizontal and vertical angles were measured variously to standard targets, to a Wild extra-large target at K, or to standard striped wands.

Slope distances were measured with electronic distance-measuring devices (EDM) mounted on the same tripod and tribrach used for the theodolite. In 1975 and 1977, distances were measured with a model 76 AGA Geodimeter using a helium-neon laser powered by a portable 12-volt, gel-cell battery. In 1982, measurements were made with a K & E Uniranger using an infrared diode signal source. Duplicate measurements with the AGA instrument could not be made in 1982 because that equipment failed to operate. In 1984, measurements were made with the K & E instrument, and 14 distances also were observed with the AGA instrument. As a rule, 12 readings were made during each pointing of an EDM toward a retroreflector. The longest and shortest values among the 12 readings were discarded and the remaining 10 averaged. The EDM was then moved off target and again repointed and the process repeated. Three independent sets, each of 10 readings, were averaged to obtain a raw distance. This distance was corrected for temperature and barometric pressure observed at each end of the line, and for instrument offset, individual retroprism offset, difference in heights of instrument and targets above their stations, and for a calibrated correction within the 10-m cyclical variation of each instrument. Most distances between stations were measured from both ends, usually on different days.

REDUCTION OF OBSERVATIONS

All corrected slope distances were converted to horizontal distances projected to the elevation of station 2 by using zenith angles corrected for curvature of the earth and refraction by air. Differences in elevation were computed from slope distances, vertical angles, and the differences in heights of instrument and targets above stations. Observed horizontal angles and distances were entered into a computer program specially designed by W.K. Smith to adjust triangles or quadrilaterals in which all angles and distances are observed (Smith and Varnes, 1987). Observations made in years prior to 1987 also were readjusted using the new computer program.

The resulting adjusted horizontal distances and angles between stations were used to calculate north and east coordinates of all stations, assuming station 4 to have coordinates 10,000 m N. and 10,000 m E., altitude 3645.4153 m (11,960.00 ft), and the azimuth of the line from station 4 to station 6 to be 155.93634 degrees. For purposes of determining all relative movements, station 4 has been assumed to be fixed both horizontally and vertically, and the azimuth from station 4 to station 6 has been assumed constant. Station 4 was selected to be the reference point because of its location somewhat upslope and east of the ridge-crest graben and its relatively great distance from steep slopes.

Distances between the stations could not be measured in 1989, owing to lack of helicopter transport of heavy EDM equipment. Therefore, computation of coordinates required that one distance be assumed constant from 1984 and used as a baseline. For this purpose, line 6-K, horizontal distance 1010.4120 m in 1984, was chosen. Gravitational spreading, if any, should be about perpendicular to line 6-K.

Table 1 shows the computed coordinates and altitudes of the survey stations at the years of observation.

MEASURED DISPLACEMENTS

Distances between most stations were measured in 1975 and 1977 with the AGA EDM and in later years with the K & E instrument. To determine total displacement of a point during the whole period of study, sets of data from the two different instruments had to be joined. This was done by using the AGA EDM measurements, and the determined characteristics of both instruments, to infer what the positions of points observed in 1975 and 1977 would have been if determined with the K & E EDM. There are unavoidable minor errors inherent in this process, but they have been minimized, so far as possible, by W.K. Smith's calibration of both instruments on a carefully measured baseline.

Horizontal and vertical relative displacements of as much as 7 cm over a 14-yr period were observed. The computed displacements are believed to be real if they exceed the observational error, which appears to be of the order of 1 to 2 cm. Figure 3 shows, by directed arrows and numbers in millimeters, the observed horizontal displacements of points relative to the fixed station 4; changes in altitude, in millimeters, are shown at the ends of the arrows. The length of time, in years, over which the displacement occurred is shown in parentheses.

Figures 4a through 4f show, graphically, details of the successive horizontal positions and altitudes at the years of observations of stations 1, 2, 3, 6, B, and K.

DISCUSSION

Except for station B, the apparent relative movements of all stations are small and some are within the probable instrumental error. Movements of stations 1, 2, 3, and K show a consistent pattern of vectors directed toward the nearest valley or steeply descending slope. The movement of station 3 at the upper edge of a very steep slope has been the greatest of all-- 7 cm outward and 3 cm downward in 14 years. Changes in altitude of all stations are less accurately determined and, hence, appear to be somewhat erratic.

Station	Coords.	1975	1977	1982	1984	1989
1	North	10113.6620	10113.6622	10113.6764	10113.6709	10113.6726
	East	9878.4854	9878.4972	9878.4789	9878.4808	9878.4768
	Alt.	3634.7641	3634.7739	3634.7718	3634.7699	3634.7678
2	North	10017.2120	10017.2078	10017.2056	10017.1941	10017.1977
	East	9822.7819	9822.7915	9822.7695	9822.7705	9822.7697
	Alt.	3639.5742	3639.5938	3639.5856	3639.5900	3639.5808
3	North	10435.7737	10435.7811	10435.7976	10435.8060	10435.8350
	East	9724.4095	9724.4441	9724.4143	9724.4071	9724.3766
	Alt.	3575.7077	3575.7291	3575.7085	3575.7058	3575.6798
4	North	10000.0000	Assumed Stable	⟶		
	East	10000.0000				
	Alt.	3645.4153				
6	North	9678.2175	9678.2199	9678.2168	9678.2088	9678.2206
	East	10143.6954	10143.6943	10143.6957	10143.6993	10143.6940
	Alt.	3630.6134	3630.6150	3630.6253	3630.6240	3630.6216
7	North				10699.8800	Not Observed
	East				7468.0806	
	Alt.				3665.1803	
B	North		11147.5259	11147.2633	11147.2431	11147.2262
	East		8417.1521	8416.7542	8416.7344	8416.7567
	Alt.		3443.3265	3443.5969	3443.5952	3443.6256
D	North					12296.9293
	East					8701.3349
	Alt.					3611.8276
K	North		9324.4839	9324.4876	9324.4726	9324.4665
	East		9197.2260	9197.2195	9197.2306	9197.2318
	Alt.		3672.9614	3672.9010	3672.9220	3672.9159

Table 1.--Coordinates and altitudes of the Bald Eagle Mountain survey stations at the years of observation.

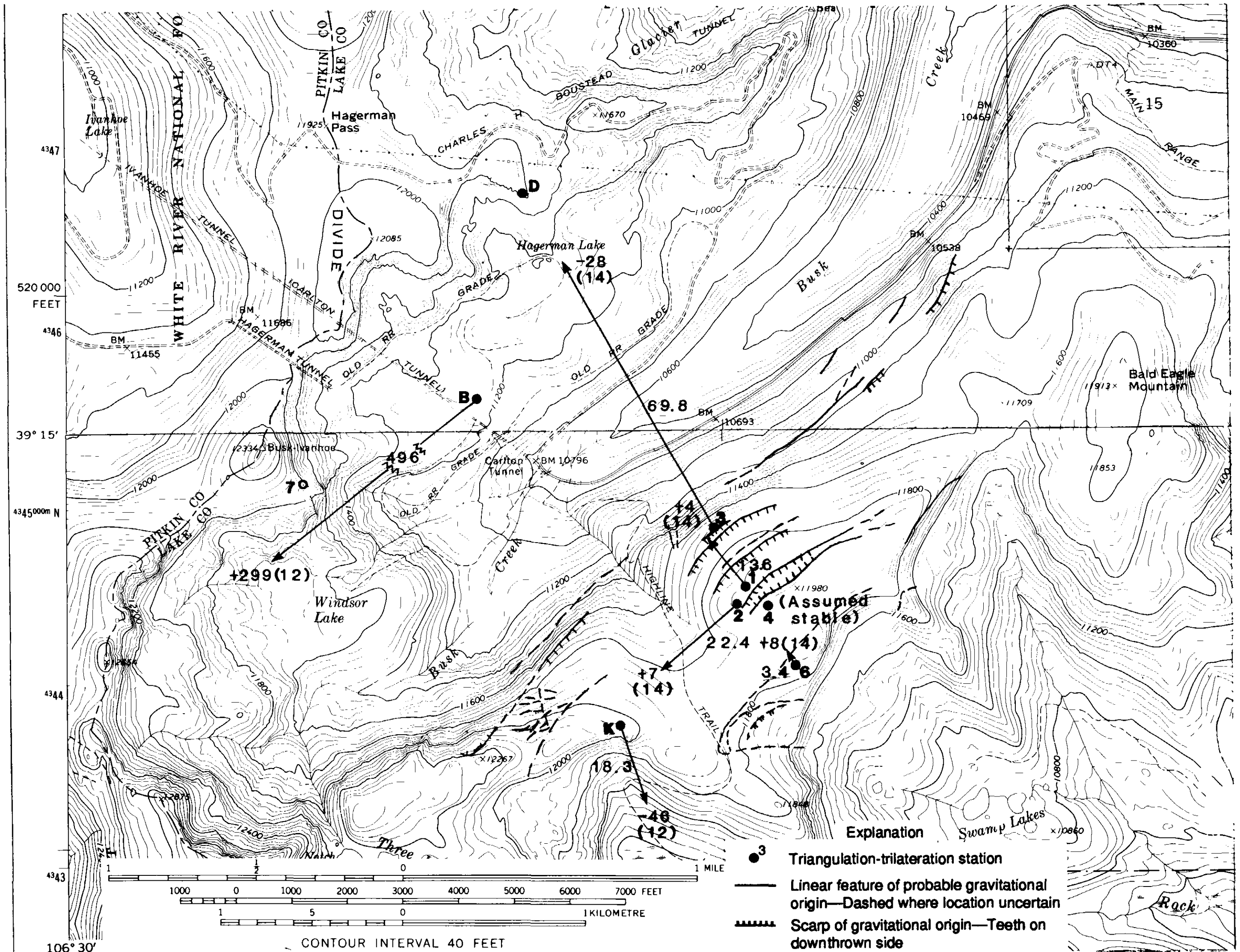


FIGURE 3.--Relative movements of the Bald Eagle Mountain survey stations. Arrows show direction of horizontal movement in mm; vertical movement in mm given at end of arrow; period of observation in years, in parentheses. All movements are relative to station 4, assumed stable; the direction of line 4-6 is assumed constant.

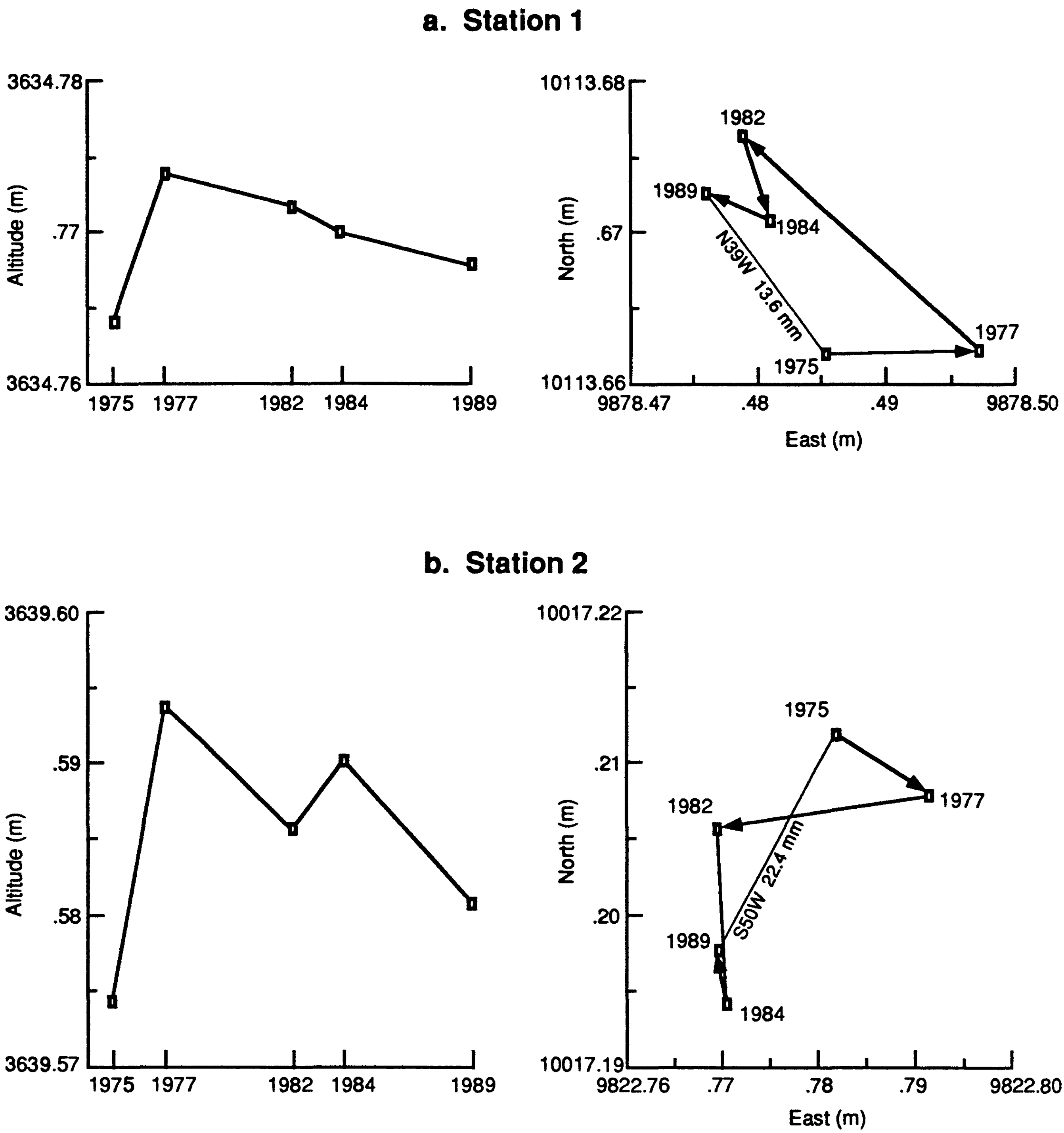
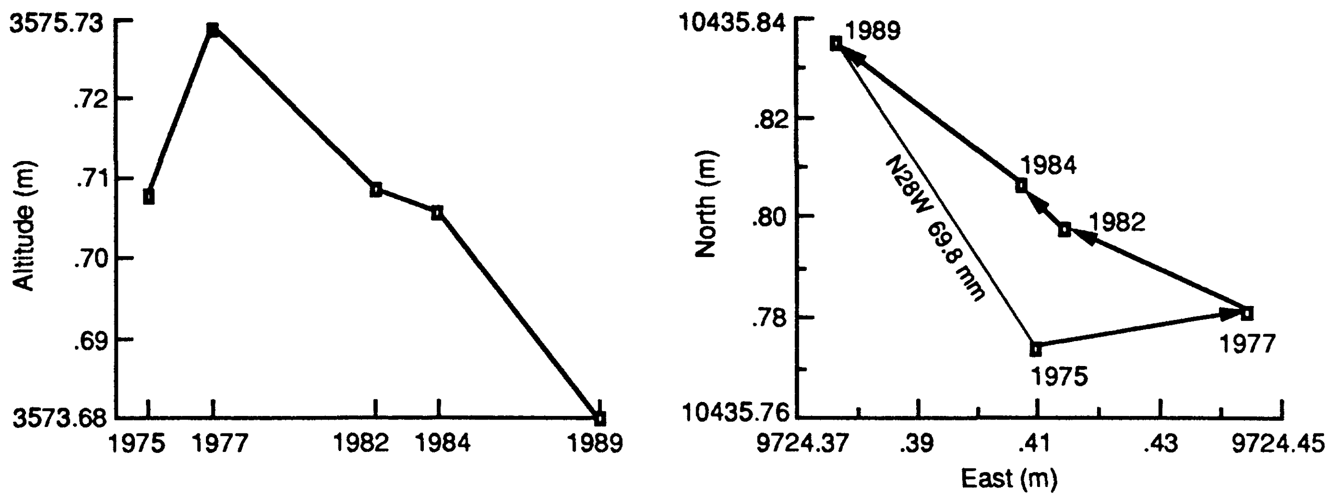
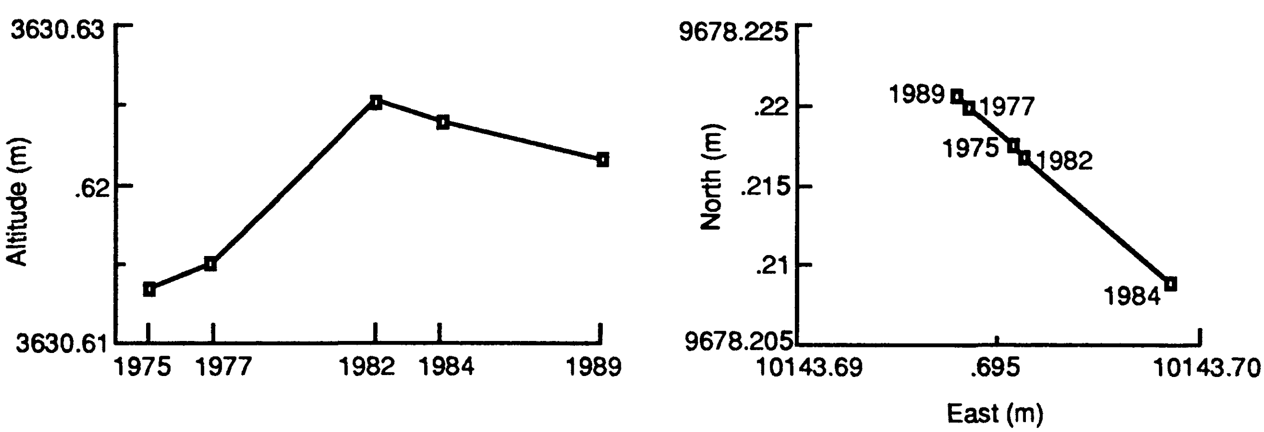


FIGURE 4.--Diagrams of the horizontal positions and altitudes of the stations at years of observation. a. Station 1, 1975-1989; b. Station 2, 1975-1989; c. Station 3, 1975-1989; d. Station 6, 1975-1989; e. Station B, 1977-1989; f. Station K, 1977-1989.

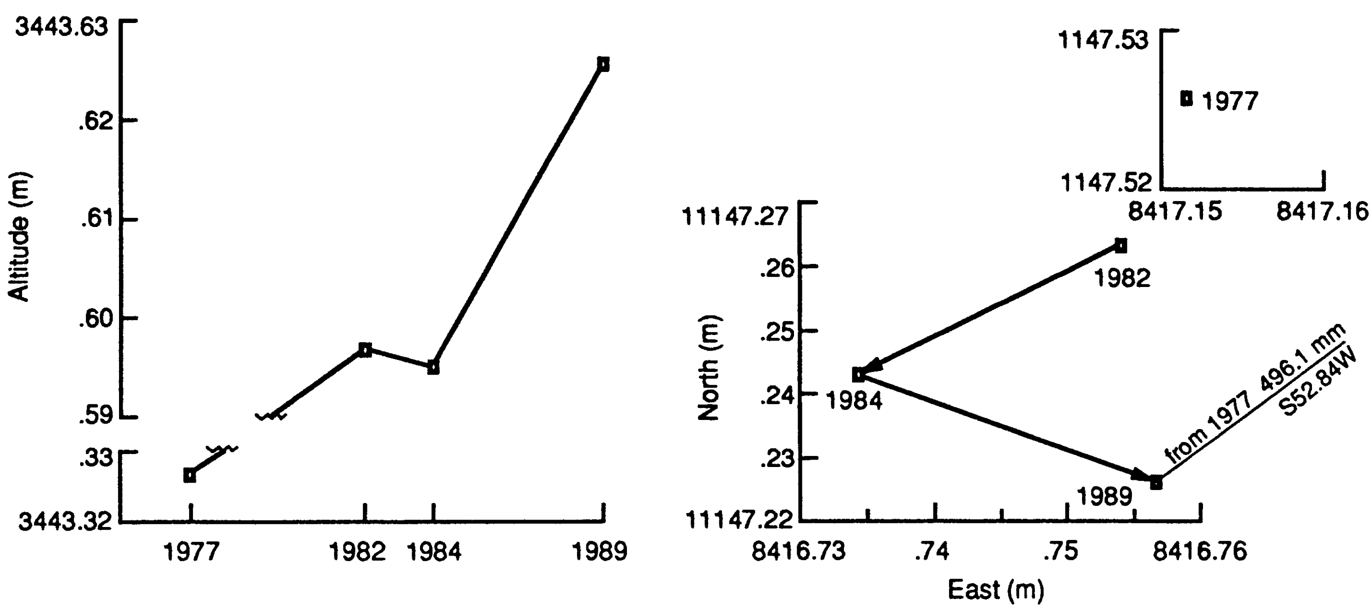
c. Station 3



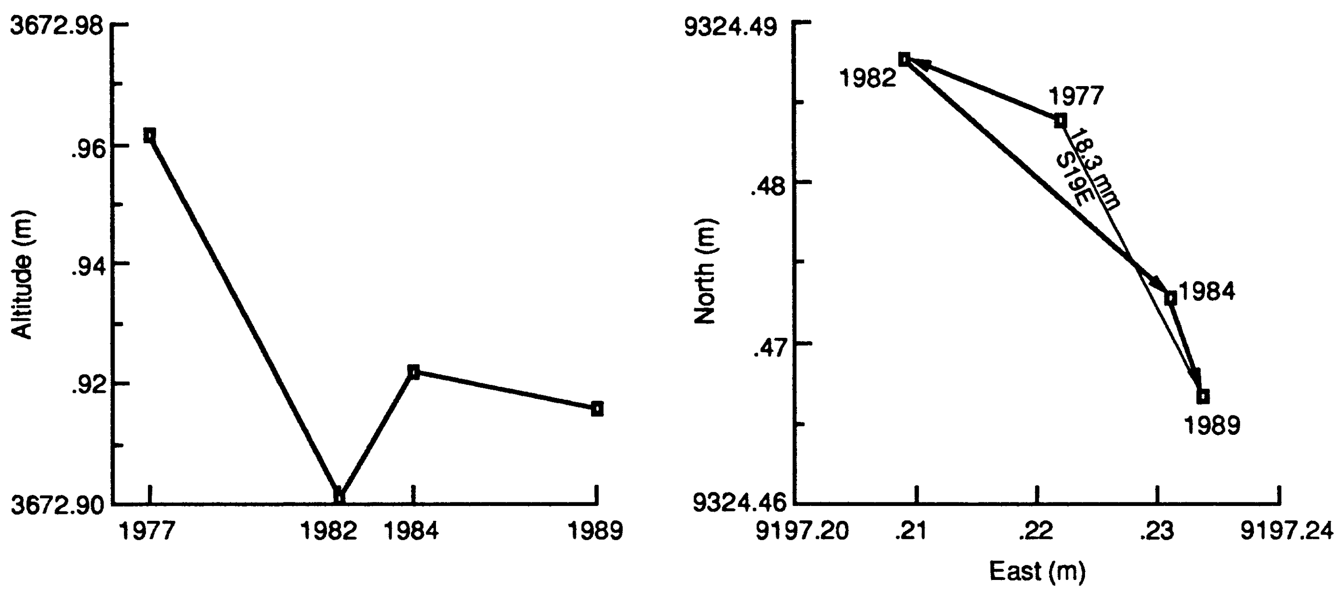
d. Station 6



e. Station B



f. Station K



Station B presents a problem. It was established in 1977 to provide a stable point west of Busk Creek to which movements in the area of trenches on the east side of the valley could be referred. Observations in 1982, from stations on the east side of the valley toward B, indicated that between 1977 and 1982 either B had moved about 50 cm to the southwest or all stations on Bald Eagle Mountain moved a comparable distance northeast. Examination of the area at B, which is a well-exposed almost flat platform of granite, showed no sign of local movements or that the station stake itself had been disturbed. However, some of the timbered and hummocky slopes west of Busk Creek, where the old railroad grade makes several loops in approaching the Hagerman Tunnel, may be on old landslide deposits of unknown stability. Station B apparently moved an additional 3 cm southward between 1982 and 1989. Also, station B is only about 100 m from being directly over the Carlton Tunnel 150 m below. We have learned that during the construction of this tunnel, areas of unstable highly fractured rock required the installation of much more timbering than was planned. Also, "the tunnel builders encountered very large cavities in the rock which were filled with liquid mud" and there were occasional large discharges of water (Cafky, 1965, p. 70-72). Because of the difficulty with station B, station 7 was established and occupied in 1984 and station D was established and occupied in 1989.

Station 7 was established in 1984 on a high granite promontory west of Busk Creek and about 0.2 mi southeast of Busk-Ivanhoe triangulation station on the Continental Divide. Adjustment of the four quadrilaterals that include station 7 indicates that the coordinates of station 7 may now be known with an error of less than 2 cm. For future reference, this station should be stable, but it is impractical to occupy without helicopter support. It was not occupied or observed in 1989. Erection of a small permanent signal at station 7, with permission of the U.S. Forest Service, would be helpful during any further work on the survey net.

In 1989, all stations except 7 were occupied and horizontal and vertical angles only observed with the T-2 theodolite. In addition, new station D was established on the west side of Busk Creek, accessible from the road over Hagerman Pass. The EDM equipment, as well as the theodolite, could be carried by back pack to this new station, so angles were observed and distances were measured from station D to stations 3 and B. These one-way distances from station D were used as a check against gross errors in the chain of quadrilaterals but were not used to adjust the 1989 observations among the other stations.

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Cafky, Morris, 1965, Colorado Midland: Rocky Mountain Railroad Club, photographs, tables, maps, 467 p.

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