SLOPE AS A DETERMINANT OF THE BOUNDARY BETWEEN THE CASCADES AND SIERRA NEVADA

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Geographers have ascribed significance to the Cascades and Sierra Nevada as discrete, natural provinces, but heretofore descriptions of the boundary between these two ranges have been vague. For example, Fenneman states, "A distinct change in the character of the Sierra-Cascade province is seen near the 40th parallel."[1] Loomis says, "The Sierra Nevada extends from the Feather River south to the Mohave Desert...."[2]

The purpose of this research is to attempt to systematically and objectively establish a slope boundary between the Cascades and Sierra Nevada. The hypothesis tested was:

Due to geologic stage and process, slopes of the Sierra Nevada will be steeper than those of the Cascades in the area where the two ranges meet.

Constructional volcanism has been occurring intermittently in the Cascades for millions of years, continuing until recent times, as witnessed by the eruptions of Lassen Paak between 1914 and 1917. Compared with the Sierra Nevada, the processes of erosion have not had a sufficient span of uninterrupted time to maturely dissect much of the region. Intermittent volcanism has thwarted the progress of erosion since mid-Tertiary and, furthermore, Cascadian streams have not had the impetus of periodic uplift to rejuvenate themselves.

In contrast, volcanism in the northern Sierra has not been extensive, and has not occurred since the Pliocene. Uplift of the Sierra Nevada continues today, as evidenced by the earthquake of 1872, and by recent faulting along the eastern scarp. Thus, the agents of erosion have been given an advantage of time in carving Sierran topography that they have not had in the Cascades.

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Study Area Delimitation

Selection of sample areas of equal size on either side of the irregular geologic boundary was awkward without a point of reference. To facilitate selection of study units, an axis was drawn approximately bisecting the zone of geologic change. This axis provided a reference line from which to measure the northwest and southeast limits of the study area. The northeast boundary was established just west of Lake Almanor. The area northeast of Lake Almanor is part of the Modoc Plateau, a volcanic upland geologically similar to the Cascades, but in general, flatter. The southwestern confines of the study area lie at the base of the foothills. The total area encompasses approximately 1,519 square miles (Figure 1).

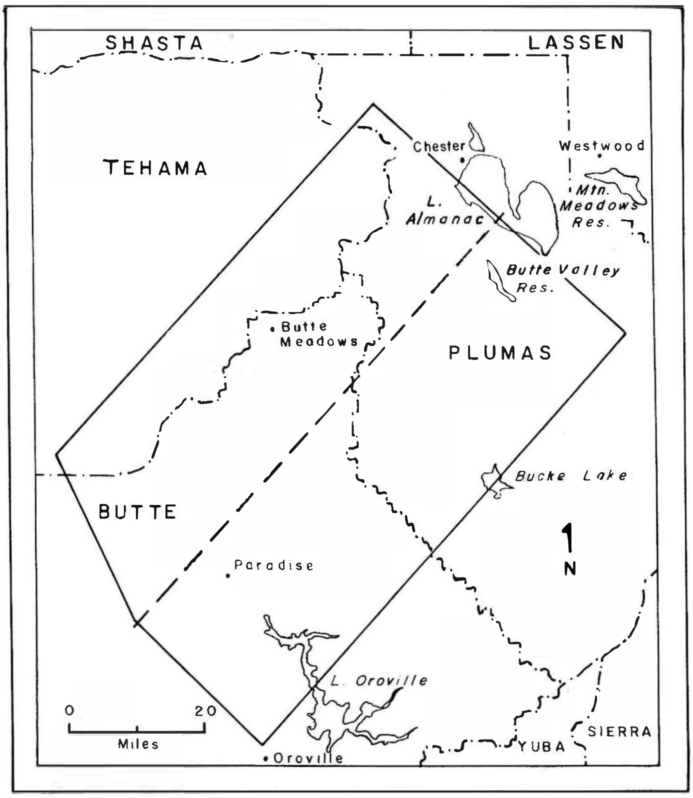

Figure 1. Study Area Boundaries and Reference Axis

A modification of Van Horn's plastic slope template and Thrower and Cooke's slope indicator technique was used to analyze the maps for slope.[3] Seven categories of percent of slope were established: (1) 0-15 percent, (2) 16-30 percent, (3) 31-45 percent, (4) 46-60 percent, (5) 61-75 percent, (6) 76-90 percent, and (7) over 90 percent. Fifteen percent increments were chosen because a range of greater than 15 percent for each category would have decreased experimental sensitivity, whereas a range of less than 15 percent would have entailed too many categories to be workable.

Template construction. For each map contour interval involved, a clear, plastic template was constructed with corresponding contour lines drawn on it for each percent slope category. To determine the spacing of lines for each percent of slope for each contour interval, the formula for determining percent of slope must be recalled. It is

$$S = \frac{v}{h}\ (100\%)$$

where v is the amount of rise or vertical distance, and h is the run, or horizontal distance. Since the map scale is 1:62,500, one inch on the map represents approximately one mile on the ground. If the topographic map indicates that a unit of terrain rises 5,280 feet in 5,280 feet of horizontal distance, the values in the formula would be

$$\frac{5{,}280}{5{,}280}\ (100\%),$$

resulting in a 100 percent slope, an angle of 45°. If the contour interval is, say, 80 feet, then 5,280 divided by 80 gives the number of lines into which one inch must be divided to represent 100 percent slope. To determine the spacing for 75 percent slope on a map with a contour interval of 80 feet, for example, we compute 75 percent of 5,280 = 3,960; 3,960 divided by 80 is 49.5, the number of lines into which one inch must be divided to represent 75 percent slope. Identical computations were made for each contour interval used and for each percent of slope category. Since the task of dividing one inch into so many contour lines was very cumbersome, the template segment was lengthened to two inches (or three or four inches), the same number of lines drawn approximately 1/50 inch apart, and the segment reduced photographically by 1/2 (or 1/3 or 1/4). Templates were also made for each *index* contour interval involved (see Figure 2).

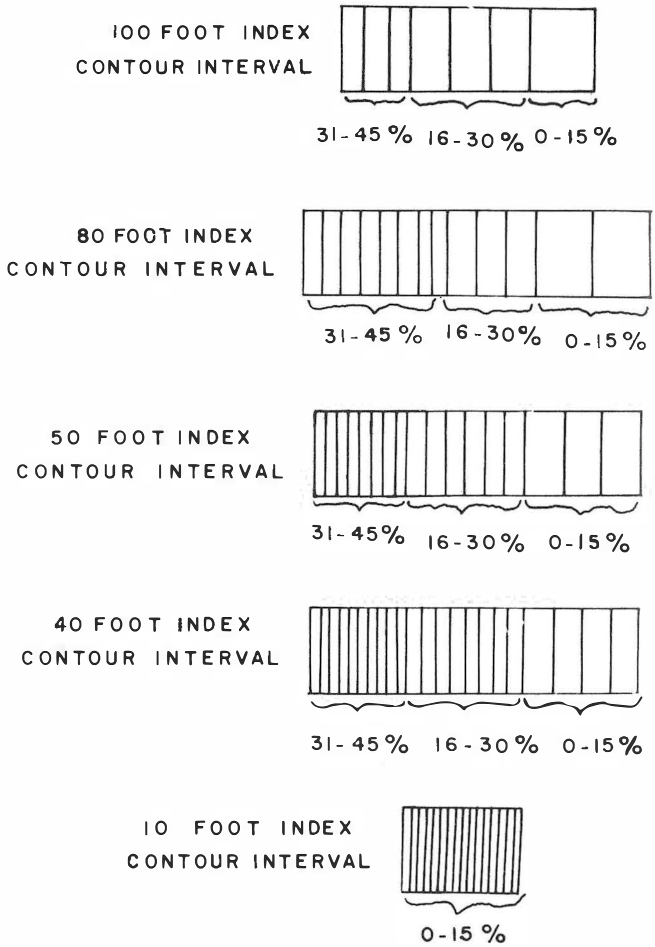

Figure 2. Sample Segments of Index Contour Interval Templates.

Map analysis. With the plastic templates prepared, actual examination of the topographic maps began. Each map was overlaid with tracing paper, and a colored pencil was selected to represent each category of percent of slope. The appropriate template was slowly moved inch by inch over each map, matching contour lines to those on the template. Beginning with 0-15 percent, all map areas where the contour spacing was the same or greater than that on the template were colored one color. The same was done with each template for each category of slope. Because of the great variability of the contour line spacing, analysis with the regular contour line templates was extremely difficult. Therefore most of the work was completed with the index contour templates, speeding the work considerably. All maps were analyzed in this manner for the entire study area. The assembled tracing paper resulted in a large slope map of the study area with each category of slope represented by a different color. The geologic boundary as shown on the California Division of Mines and Geology geologic map sheets of Chico and Westwood, and the reference axis were then superimposed on the map.

Data Preparation

To facilitate analysis of the colored tracing paper map, the colors were converted to numerical data. Each color was assigned a value as follows:

Number	Color	Percent Category
1	Yellow	0-15
2	Light green	16-30
3	Purple	31-45
4	Orange	46-60
5	Dark green	61-75
6	Red	76-90
7	Dark blue	over 90

With each integer representing the mid-point of a category, the following values were assigned to the following percentages of slope:

Value	Percent of Slope
1.0	7.5
1.5	15.0
2.0	22.5
2.5	30.0
3.0	37.5
3.5	45.0
4.0	52.5
4.5	60.0
5.0	67.5
5.5	75.0
6.0	82.5
6.5	90.0
over 6.5	over 90.0

The entire map was overlain by a tracing paper grid of four-inch cells. On a separate piece of frosted plastic film, a single cell 4 inches square was further subdivided into cells 4 inches square. Every other 0.2 inch cell was carefully cut out with scissors. This 4-inch square guide was placed on the larger grid of 4-inch squares, one square at a time, instantly converting each into a 4-inch cell of 400, 0.2-inch cells. Since every other cell had been cut out, the underlying slope map was exposed through half, or 200, of the small cells.

The predominant color exposed through each of these cells was determined, and the correct number for the percent of slope represented was written in pencil through each cell on the tracing paper beneath. The 4-inch grid was then rotated one quarter of a turn and the remaining 200 cells marked in the same way. When all the large cells had been marked, the entire area had been assigned one number for every 0.2-inch cell. Thus, the values could be aggregated for any size area desired, as amall as 0.2 inch square, or as large as the entire study area.

A working grid of one inch cells (approximately one square mile) was used in the actual analysis. A coordinate system of letters and numbers was established to designate rows and columns of one inch cells. The 32 rows were assigned letters from left to right, A through Z, and AA through FF. The 50 columns were assigned numbers from 1 to 50. Because of the dimensions and shape of the study area, some marginal cells were smaller than one square inch. Except for these, and a few cells which overlaid small areas not included in analysis (parts of lakes, rivers, etc.) each cell contained 25 numbers.

An average value for each cell was found. The numbers in each cell were summed and divided by the number of values within the cell, resulting in an average slope value for each cell. Next, average slope values for each column were computed by summing the cell averages and dividing by the number of cells in the column.

Testing the Hypothesis

When all column averages had been found, a comparison of slope values could be made from one side of the axis to the other. The Cascade side of the axis included columns A through P (excluding small patches of Quaternary alluvium), and the Sierra side, columns Q through FF. The average slope value for each side was computed by summing the column averages and dividing by the number of columns.

A more precise analysis was then made by comparing average values from one side of the geologic boundary to the other. All values for each column, partial column, whole cells, and parts of cells covering Cascadian rock were summed and averaged. The same was done for the Sierra Nevada. This supplied the basic information to support or reject the hypothesis that slopes of the Sierra are steeper than those of the Cascades in the boundary region.

To establish a slope boundary a row-by-row analysis was done. A table of average cell values for each row was prepared so that each row from left to right could be studied for significant changes in slope values. Each row was analyzed for significant breaks or changes in percent of slope, and for slope trends, using the following operational definitions:

1. Significant change - The slope value of a cell differs by at least one point (15%) from the value of the cell immediately preceding and following it in a row.

2. Trend - Each 3-cell segment immediately preceding or following a significant change is uninterrupted by another significant change (the values do not vary by one point, 15%, or more).

Every significant change and the difference in slope values was noted in each row. Every slope trend and its average slope value was indicated also.

Intuitive boundary. Without refernnce to or consideration of the geologic boundary, an "intuitive" boundary (or boundaries) was established as suggested by the data. Only significant changes accompanied by slope trends were considered. Each significant change and trend, represented by a dot, was plotted on a map of the study area which did not show the geologic interface between the Cascades and Sierra Nevada. Straight lines were drawn to connect the dots from row to row where they appeared close together or were in some way obviously aligned in a NE-SW direction, roughly paralleling the trend of the geologic boundary. Some dots appeared to fit into a boundary but were not connected because of the distance between them. A boundary was not interpolated between significant changes of more than approximately two or three miles perpendicular in either direction. Because many rows contained more than one significant change accompanied by a trend, more than one intuitive boundary emerged. A Plus (+) or a minus (-) sign on either side of the intuitive boundaries indicates whether the slope trend is steeper or less steep.

Findings and Conclusions:
Regarding the Problem

The problem or purpose of the research was to attempt to establish a slope boundary between the Cascades and Sierra Nevada. Figure 3 shows the results. The solid, black lines connecting the dots represent intuitive boundaries. Rather than finding one continuous boundary, the data indicated several short slope boundaries, or boundary segments. The longest segments, between rows 7 through 17, columns Q through V (Boundary A), and rows 18 through 30, columns W through Y (Boundary B) are approximately 15 miles long and 12-1/2 miles long respectively. Shorter segments appear between rows 15 through 22, columns Y through BB (Boundary C); rows 25 through 31, columns AA through CC (Boundary D); and rows 11 through 17, columns C through D (Boundary E). Three very short segments connect only three dots each. These occur at rows 19 through 21, columns A through B; rows 15 through 17, column E; and rows 30 through 32, column N. Eight segments connect only two dots, and the remaining dots are unconnected.

All of the boundary segments except for three "2-dot" segments trend in a northeast-southwest direction, approximately

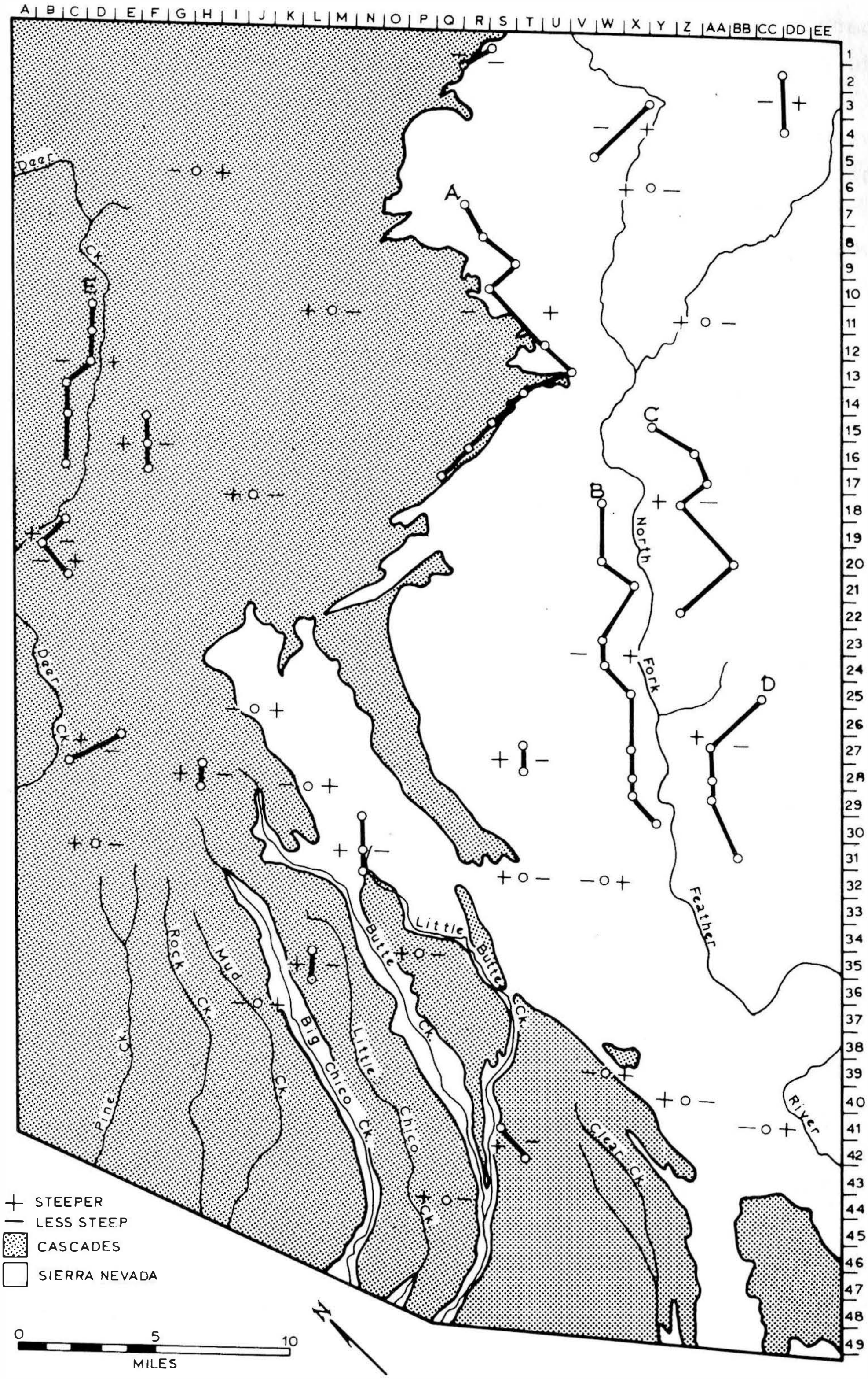

Figure 3. Drainage, Geologic Interface, and Intuitive Slope Boundaries in Study Area.

paralleling the geologic interface. The 16 unconnected dots do not seem to fit into any boundary scheme.

None of these intuitive boundaries is long enough to stand by itself as a salient slope boundary distinguishing one mountain province from the other, and the existence of other boundary segments seemingly scattered throughout the study area would tend to invalidate any preference for one boundary over another.

A more continuous boundary might have emerged by using some value of less than one point (15%) to represent a significant change in slope. For example, if all changes of, say, 0.8 or greater had been recorded, a satisfactory boundary might have been achieved. However, such a statistical maneuver would undoubtedly compound the problem of too many boundary segments, making justification of any one difficult.

Some attention should be given to the possibility that differences in slope characteristics may be attributable to factors other than broad geologic differences. Certainly other factors influence slope development. Exposure, differential resistance of rock to weathering, vegetation, and climate, for example, can have a substantial effect on slope form and steepness. However, these are usually locally manifested. Exposure may be the principal reason for a steep slope on a particular hill or ridge, but it is unlikely that conditions of exposure would be uniform throughout the entire Sierra or Cascade part of the study area and, additionally, contrast significantly with the other side.

Rock composition and rock type vary greatly within both the Sierra Nevada and the Cascades. Differential weathering of rocks of different types could be found at many places within each part of the study area, and would not likely account for overall differences.

Climate and vegetation are relatively uniform throughout the Sierra Nevada and Cascades. Peculiar micro-climatic conditions could definitely affect degree of slope, but again, this would be localized within the region. Vegetation changes with elevation, but is *broadly* similar in both ranges, and would not likely account for a difference in slope from one range to the other.

We also need not reject the possibility that the change from one lithic unit to another influenced the change in slope characteristics, but the other slope boundaries must also be accounted for. A partial explanation can be seen on Figure 3. It is clear that the Feather River has exerted a great influence on slope steepness. Slope boundaries B, C, and D parallel the course of the North Fork of the Feather River. The slopes trend (left to right) from less steep (-), to steep (+), to steep (+), to less steep (-), indication clearly the steep, plunging canyon walls. The same effect, although less dramatic, can be seen in the northwest corner along Deer Creek (Boundary E). The existence of these river canyons has "pulled" the intuitive slope boundary away from the influence of the geologic interface. Interestingly, foothill streams such as Pine Creek, Rock Creek, Mud Creek, Big and Little Chico Creeks, Butte Creek, and Clear Creek have not demonstrated the same control on slope development except for points along row 37 and 39 where the transition from less steep to steep lies almost precisely upon the line separating Cascadian from Sierran rock. Various other points of slope change which are unaccounted for must be explained by some other phenomena, perhaps exposure, vegetation, etc., as mentioned before.

Findings and Conclusions:
Regarding the Methodology

As a technique that can be employed by an individual, slope analysis by the present method is rigorous and thorough, particularly when the entire study area is analyzed rather than samples. However, there are instances of generalization in the methodology which should be mentioned.

The construction of contour line templates is tedious and difficult. It involves drawing many equally spaced lines by hand in a space of one to three inches. The actual width of each line varies when drawn by hand so that complete uniformity of line spacing and width is impossible to achieve. This may result in a slight margin of error, the degree of which is not known, but which is assumed to be negligible.

Also, since the topographic maps were analyzed mainly by templates corresponding to the index contour spacing, some generalization of percent of slope unavoidably occurred within the index contour lines.

In converting the color data to numerical data, a value was assigned according to the color mode within each 0.2 inch square cell. This, too, was a generalization, but only to an area 0.2 inch square, which is very small datum unit for a study area of approximately 1,500 square miles.

Recommendations

With regard to the hypothesis that slopes of the Sierra are steeper than those of the Cascades, it would be useful and informative to compare slopes from sample areas other than boundary segments to determine if slope characteristics in the boundary region persist throughout the two ranges.

The idea of slope as a boundary between geologically dissimilar ranges need not be discarded. We have seen that at least a partial slope boundary coincides with the geologic boundary (Boundary A, Fig. 3). Another similar experimental situation might well produce the expected results. For example, the same problem is applicable to the Klamath and Cascade Mountains. The geologic history of the Klamath Mountains is basically that of the Sierra. the same technique of slope analysis could be applied in an attempt to establish a slope boundary there.

NOTES

[1]Fenneman, Nevin M., *Physiography of Western United States*, McGraw-Hill Company, Inc. (1971), p. 417.

[2]Loomis, Frederic B., *Physiography of the United States*, New York: Doubleday, Doran and Company, Inc. (1938), p. 312.

[3]Thrower, Norman J. W. and Ronald U. Cooks, "Scales for Determining Slope from Topographic Maps," *The Professional Geographer* (May, 1968), pp. 181-86.

See Also: Van Horn, Richard, "Slope Map of the Sugar House Quadrangle, Salt Lake County, Utah" (1972), U.S.G.S. Map 1-766-C.