Analysis of Linear Features Mapped From Landsat Images of the Cascade Range, Washington, Oregon, and California

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Abstract

Computer-compatible tapes of 13 Landsat multispectral scanner (MSS) images covering the Cascade Range and surrounding region from the Canadian border into northern California were used to prepare contrast-stretched and edge-enhanced 1:800,000-scale positive film transparencies for mapping linear features. Linear features are relatively short, distinct, non-cultural straight lines that are mappable Landsat MSS images. They represent linear topography, such as cliffs, slope breaks, narrow ridges, and stream valley segments, that is interpreted as reflecting the influence of local geologic structure, including faults, joints, foliation, and the strike of tilted strata. A total of 5,064 linear features were mapped in the Cascade Range region.

Statistical methods were used to examine the length and orientation characteristics of the linear feature data. The linear features range from 0.5 to 27 km long and have a mean length of 3.84 km and a prominant mode at 2.8 km. The abundance of linear features is expected to increase exponentially with decreasing length; because those linear features shorter than the modal length (2.8 km) do not fit this model, they were excluded from the strike-frequency analysis. Strike-frequency analysis revealed 7 trend intervals that are statistically important at the 90% significance level. These intervals are N.42°-61°W., N.20°-39°W., N.10°E.-N.12°W., N.14°-27°E. N.36°-38°E., N.62°-72°E., and N.78°-82°E.

Maps were prepared to show the geographical distribution of the linear features in the important trend intervals. Contour maps were prepared to enhance the geographical density variations (concentration patterns) of the linear features in the important trend intervals.

The concentration map of all the mapped linear features shows a prominent change from relatively high concentration to relatively low concentration southward across a west-northwest trending line between lat. 43°-44° N. This concentration boundary is on trend with the High Lava Plains province, a late Cenozoic volcanic terrain that marks the northern termination of characteristic basin and range structure and physiography east of the Cascade Range. The concentration domain boundary suggests that this structural trend continues west-northwestward across the Cascade Range, and the projection of the trend west-northwestward to the Pacific Ocean is progressively marked by (1) the southern termination of the Willamette depression, (2) the northwestward termination of the Eugene-Denio fault zone, (3) the southward termination of mapped Tertiary intrusive bodies in the Coast Range, (4) a saddle in the Coast Range gravity high, and (5) a conspicuous indentation in the continental shelf at the south end of Hecta Bank.

Introduction

This report describes the preparation of computer-enhanced Landsat multispectral scanner (MSS) images and their interpretation for linear features in the Cascade Range of Washington, Oregon, and California, and the surrounding region, and presents the results of computer analyses of the linear feature data for regional characteristics and patterns. Statistical methods were used to determine the most prominent orientations of linear features and their frequency distribution according to length. Maps show the geographical distribution of the linear features in the most prominent trend intervals, and contour maps show the density distribution of the linear features in these trend intervals. Geologic interpretation of the results of the linear features analyses have not been completed; however, comments are presented on the possible geologic importance of a pattern shown by the concentration map of all mapped linear features.

This is the first study to investigate the linear features or lineaments of the entire Cascade region in detail with specially-prepared, computer-enhanced Landsat MSS images . Venkatakrishnan and others (1980) have studied the "geological linears" mapped from Landsat MSS and side-looking radar images and small-scale aerial photographs of the northern part of the Cascades in Oregon.

Landsat Images and Image Processing

Computer-compatible tapes (CCT) of 13 Landsat MSS scenes covering the Casacde Range from the Canadian border on the north into northern California on the south were obtained from the EROS Data Center in Sioux Falls, South Dakota (Fig. 1). Most of the scenes were acquired in the fall, so very little snow appears on the the images, and the solar elevation angle is moderate. The latter produces a modest shadow-enhancement of topographic features (Table 1). The CCTs were processed digitally in the Geophysics Remote Sensing Laboratory of the U.S. Geological Survey, Denver, Colorado, to produce computer-enhanced positive film transparencies of each of the four spectral bands of data at a scale of 1:800,000. Two types of enhanced images were produced for each spectral band of each scene.

One set of enhanced images was prepared by contrast-stretching (Rowan and others, 1974, p.6) each band of digital data using a 2% bilinear stretch about the mean data number (DN) value to take full advantage of the 0-255 dynamic range of the film. This stretch sets the first 2% of the lowest DN values to 0, the mean DN value to 127, and the last 2% of the highest DN to 255, and stretches the intermediate DN linearly between these fixed points. The second set of enhanced images was processed to enhance the high frequency variations in the DN of spatially-related pixels. This enhancement technique has the effect of enhancing the edges between tonal boundaries on the images. The algorithm for the edge enhancement is illustrated in Knepper (1982). The edge-enhanced images were also contrast-stretched using a 2% bilinear stretch before writing the digital data to film.

Image Interpretation

The term "linear feature", as used in this report, refers to the relatively short, distinct, non-cultural straight lines that are mappable on

Landsat MSS images. For each of the 13 Landsat scenes covering the Cascade Range, the linear features were photogeologically mapped onto a clear mylar overlay that was transferred from one enhanced image to another until no additional linear features could be found. These were then transferred to 1:250,000-scale topographic maps. Linear features corresponding to obvious cultural features were removed. The compilation of linear features was digitized for subsequent computer analysis and plotting.

A total of 5,064 linear features were mapped (Fig. A1, Appendix A). From their expression on the images and their location on the topographic maps, most of the linear features appear to represent linear topography, such as cliffs, slope breaks, narrow ridges, and stream valley segments. The evolution of linear topography is strongly influenced by local geologic structures, including faults, joints, foliation, and the strike of tilted strata. The underlying assumption of linear features analysis is that linear features provide a regional sample of these structural features and that regional variations in trends and patterns of linear features can be interpreted in a geologic or tectonic context.

Some of the mapped linear features are expressed on the images as sharp tonal boundaries that do not appear to be related to the topography. These linear features are caused by spectral differences between adjacent rock or soil types or between areas with different vegetation types or densities. Because these boundaries are so straight, they are also interpreted as reflecting local geologic structure. For practical reasons, no attempt was made to classify the linear features on the linear features map.

The interpretation of linear features on Landsat MSS images is a relatively objective process because they are sharply expressed and require little judgement in determining their extent and location and, indeed, their existence. In addition, the analysis procedures used here minimize the importance of individual linear features and emphasize the regional patterns that may be present in the data. This approach, then, is relatively insensitive to occasional errors of omission and commission in mapping .

Linear Feature Analysis

The purpose of linear features analysis is to identify natural groupings of linear features according to length, orientation, and geographic distribution. The analysis techniques used in this investigation are described in detail by Sawatzky and Raines (1981) and are summarized by Knepper (1983). Length-frequency analysis helps to determine the minimum length of linear features that can be confidently identified throughout the entire study area. Strike-frequency analysis defines important groups of linear features according to orientation. Regional patterns formed by various subsets of the linear feature data can be displayed with either location maps or contour maps of density distributions.

Length-Frequency Analysis

Intuitively, the abundance of linear features should increase exponentially toward the shorter lengths, approximating a log normal distribution. The linear features of the Cascade Range show a length-frequency distribution (Fig. 2) typical for linear features mapped from MSS images, and for fractures mapped from aerial photos (Podwysocki, 1974). The distribution is approximately log normal at longer lengths, but is characterized by a prominent mode at about 2.8 kilometers, below which the abundance of mapped linear features decreases rapidly with decreasing length. This departure from the anticipated log normal distribution curve marks the shortest linear feature to be included in the regional sample.

The rapidly decreasing abundance of mapped linear features with decreasing length below 2.8 km is largely controlled by the resolution of the Landsat MSS (80 m); other factors, such as the solar elevation and inclination angles, the time of year the image was acquired, the scale and quality of the images, and the overall morphology of the terrain, also contribute to exact location of the mode. If the distribution of linear topography, and linear features, is indeed log normal, then the linear features shorter than the mode are an incomplete sample of linear topography and should not be included in statistical analyses for regional characteristics of the linear feature data.

Strike-Frequency Analysis

Strike-frequency analysis is a statistical method to define frequently occurring orientations of linear features. These orientations or trends may reflect regional structural patterns related to the tectonic development of the region. The mathamatical basis of the method is discussed in detail by Sawatzky and Raines (1981). The method counts the number of linear features (frequency) with orientations in each of 180 possible 1-degree intervals and calculates the significance level of each frequency. From experience, a 90% significance level was selected before running the analyses as a suitable division between regionally important trends and those that are probably not of regional significance.

Two strike-frequency analyses were conducted on the linear feature data of the Cascade Range. Both analyses used only the linear features longer than 3 kilometers as discussed above. The first analysis is based strictly on the number of linear features in each of the 180 possible trends. In the second analysis, each linear feature was weighted proportional to its length. The results of these analyses are shown in Figures 3 and 4.

Identification of the important trend intervals was based on a visual examination of the strike-frequency histograms. An important trend interval was defined as a maximum or group of maxima bounded by a relatively broad interval of minima; narrow minima intervals within a cluster of maxima were disregarded. The appropriateness of selections containing groups of maxima, such as the interval N.20°-39°W., was checked by plotting the linear features in the individual maxima and looking for prominent differences in their geographic distribution; a lack of any difference in the geographic distribution suggests that the individual maxima may be grouped together into a single trend interval.

The important trend intervals in the Cascade Range data are shown in Table 2. All of the maxima in the unweighted analysis are also maxima in the length-weighted analysis. However, some additional maxima, such as the interval N.41°-58°W., are only present in the length-weighted analysis.

Linear Feature and Concentration Maps

Strike-frequency analysis helps to identify groups of linear features that are probably of regional importance because of their common orientation and high frequency of occurrence. But these analyses do not indicate how the linear features within each group are distributed throughout the region. This aspect of linear features analysis is extremely important if regional patterns of linear features reflecting tectonic features or terranes of differing structural characteristics are to be recognized. Maps of the linear features in each of the selected trend intervals are in Appendix A.

Contour maps showing the areal density of linear features often enhance subtle concentration patterns that are difficult to interpret from the linear feature maps alone. Figure B1 (Appendix B) is a concentration map of all the linear features mapped in the study. This map was prepared from a contourable grid of linear feature concentrations formed by passing a 55 X 55 kilometer smoothing cell through the linear feature data in 5 kilometer increments and counting the length of the linear features that fall within the smoothing cell at each increment. The counts at each increment were then normalized to length of linear features in kilometers per 100 square kilometers (Sawatzky, 1984) and contoured. Contour maps of the concentrations of the linear features in each of the selected trend intervals were generated by the same procedure and are in Appendix B.

Preliminary Observations

The purpose of this report is to present the results of length-frequency and strike-frequency analyses of linear features mapped from computer-enhanced Landsat MSS images of the Cascade Range region. The linear feature and linear feature concentration maps (Appendices A and B) show the geographical distribution of the linear features in trend intervals identified during strike-frequency analysis. The interpretation of the geologic or tectonic meaning of the distribution patterns on these maps is presently incomplete. However, one pattern of linear feature concentrations deserves special mention.

The most prominent pattern on the concentration map of all the mapped linear features (Fig.B1, Appendix B) is the overall change from relatively high concentrations to low concentrations between 43° and 44° N. latitude. This concentration domain boundary occurs approximately where two Landsat images on the north overlap two images on the south, suggesting that the difference in linear feature concentrations might be due to northeast-to-southwest differences in the images used in the mapping. However, for the eastern two-thirds of the ground swath, the image boundary is between images acquired on the same pass, only a few tens of seconds apart, and there is no visible difference in the processed images. The image boundary for the western one-third of the ground swath is between images acquired about two years apart, but only 11 days different in the time of year, so there was almost no difference in the solar elevation and inclination angles during data acquisition. These computer-enhanced images also show no visible differences that could account for differences in the number of linear features that were mapped. Consequently, it is concluded that the approximate correspondance between the linear feature concentration boundary and the image boundaries is a coincidence.

The exact trend and location of the break between the concentration domains is subject to some latitude in interpretation; however, it appears that the concentration boundary lies along the strike of a prominent west-northwest trending alignment of upper Cenozoic volcanic rocks extending from the Snake River Plain in southern Idaho northwestward to the Cascade Range (Fig. 5). This zone, the High Lava Plains (HLP), has had a complex Cenozoic structural and volcanic history that is summarized by Christiansen and McKee (1978).

The HLP marks the northern margin of basin and range faulting in central Oregon. Along this margin, east-west extension in the Great Basin was transformed into west-northwest trending en echelon faults and northeast-trending faults of the Brothers fault zone. The pattern of faults along the Brothers fault zone suggests an underlying right lateral shear zone trending N.60°W. (Lawrence, 1976). Basaltic rocks of late Miocene to Quaternary age predominate in the HLP, although ash-flow tuffs and rhyolitic domes are also abundant. The relatively uniformly scattered rhyolite domes in the High Lava Plains show a progressive decrease in age from about 10 m.y. in the east to about 0.6 m.y. in the vicinity of Newberry Caldera in the west (MacLeod and others, 1976). This west-northwestward progression of rhyolitic volcanism is apparently related to the outward propagation of faulting and volcanism toward the margins of the basin and range province during the latter part of the Cenozoic (Christiansen and McKee, 1978, p.300).

Current thinking suggests that the HLP structural and volcanic trend does not extend west-northwestward across the Cascade Range. Instead, the Brothers fault zone is interpreted to take a prominent swing to the north to apparently join the more northerly trending faults associated with the eastern side of the High Cascades depression (Lawrence, 1976). The concentration map of all the linear features (Fig. 5) suggests that the boundary between tectonic regimes may not terminate at the western end of the High Lava Plains, but extends across the Cascade Range. Furthermore, the projection of the trend west-northwestward from the linear features study area to the Pacific coast corresponds with geological and geophysical data suggestive of a possible through-going structural discontinuity: (1) the southern termination of the Willamette depression, (2) the northwestward termination of the Eugene-Denio fault zone (Lawrence, 1976), (3) the southward termination and outcrop geometry of Tertiary mafic intrusive bodies in the Coast Range province, (4) a conspicuous saddle in the Coast Range gravity high (U.S. Geological Survey, 1964),and (5) the indentation in the continental shelf off at the south end of Hecta Bank (Fig. 5).

References

Christiansen, R.L, and McKee, E.H., 1978, Late Cenozoic volcanic and tectonic evolution of the Great Basin and Columbia Intermontane regions, in, Smith, R.B., and Eaton, G.P.,eds., Cenozoic tectonics and regional geophysics of the western cordillera: Geological Society of America Memoir 152, p.283-311.

King, P.B., and Beikman, H.M., 1974, Geologic map of the United States: U.S. Geological Survey map, scale 1:2,500,000.

Knepper, Daniel H., Jr., 1982, Lineaments derived from analysis of linear features mapped from LANDSAT images of the Four Corners region of the southwestern United States: U.S. Geological Survey Open-File Report 82-849,79p.

______________________, 1983, Summary of some analysis techniques for linear features with examples from the Cascade Range: IEEE Digest, v. 2, p.6.1-6.5.

Lawrence, R.D., 1976, Strike-slip faulting terminates the Basin and Range province in Oregon: Geological Society of America Bulletin, v.87, no.6, p.846-850.

MacLeod, N.S., Walker, G.W., and Mckee, E.H., 1976, Geothermal significance of eastward increase in age of upper Cenozoic rhyolitic domes in southeastern Oregon, in, Proceedings, Second United Nations symposium on the development and use of geothermal resources, Vol. 1; Washington, D.C., U.S. Goverment Printing Office, p.465-474.

Podwysocki, M.H., 1974, An analysis of fracture trace patterns in areas of flat-lying sedimentary rocks for the detection of buried geologic structures: NASA Goddard Space Flight Center Document X-923-74-200, 67p.

Rowan, L.C., Wetlaufer, P.H., Goetz, A.F.H., Billingsley, F.C., and Stewart, J.H., 1974, Discrimination of rock types and detection of hydrothermally altered areas in south-central Nevada by use of computer-enhanced ERTS images: U.S. Geological Survey Professional Paper 883, 35p.

Sawatzky, D.L., 1984, User's manual for LINANL, LINear Features ANaLysis Programs: U.S. Geological Survey Open-File Report (in press).

Sawatzky, D.L., and Raines, G.L., 1981, Geologic uses of linear feature maps from small-scale imagery: Proceedings of Third International Conference on Basement Tectonics, p.91-100.

U.S. Geological Survey, 1964, Bouguer gravity anomaly map of the United States: U.S.Geological Survey map, scale 1:2,500,000.

Venkatakrishnan, Remesh, Bond, J.G., and Kauffman, J.D., 1980,Geological Linears of the Northern Part of the Cascade Range, Oregon: State of Oregon, Department of Mineral Industries Special Paper 12, 25p.

Table 1. Date of acquisition and solar illumination characteristics of 13 Landsat MSS scenes of the Cascade Range and surrounding region.

SCENE ID	DATE ACQUIRED	SOLAR AZIMUTH	SOLAR ELEVATION
1075-18164	6 OCT 1972	149°	39°
1077-18254	8 OCT 1972	155°	32°
1077-18260	8 OCT 1972	154°	33°
1077-18263	8 OCT 1972	153°	34°
1077-18265	8 OCT 1972	152°	35°
1690-18245	13 JUN 1974	130°	57°
1797-18162	28 SEPT 1974	145°	39°
1797-18165	28 SEPT 1974	144°	40°
2596-18120	9 SEPT 1976	139°	41°
2630-18000	30 OCT 1976	147°	32°
2630-18002	30 OCT 1976	146°	33°
2630-18005	30 OCT 1976	145°	34°
2630-18011	30 OCT 1976	144°	35°

Table 2. Regionally important linear feature trend intervals of the Cascade Range and surrounding region defined by statistically significant maxima or groups of maxima occurring on the length-weighted strike-frequency histogram. A * indicates that the trend interval is not reflected in the unweighted analysis.

N.42°-61°W.
*N.20°-39°W.
N.10°E.-N.12°W.
*N.14°-27°E.
*N.36°-38°E.
N.62°-72°E.
*N.78°-82°E.

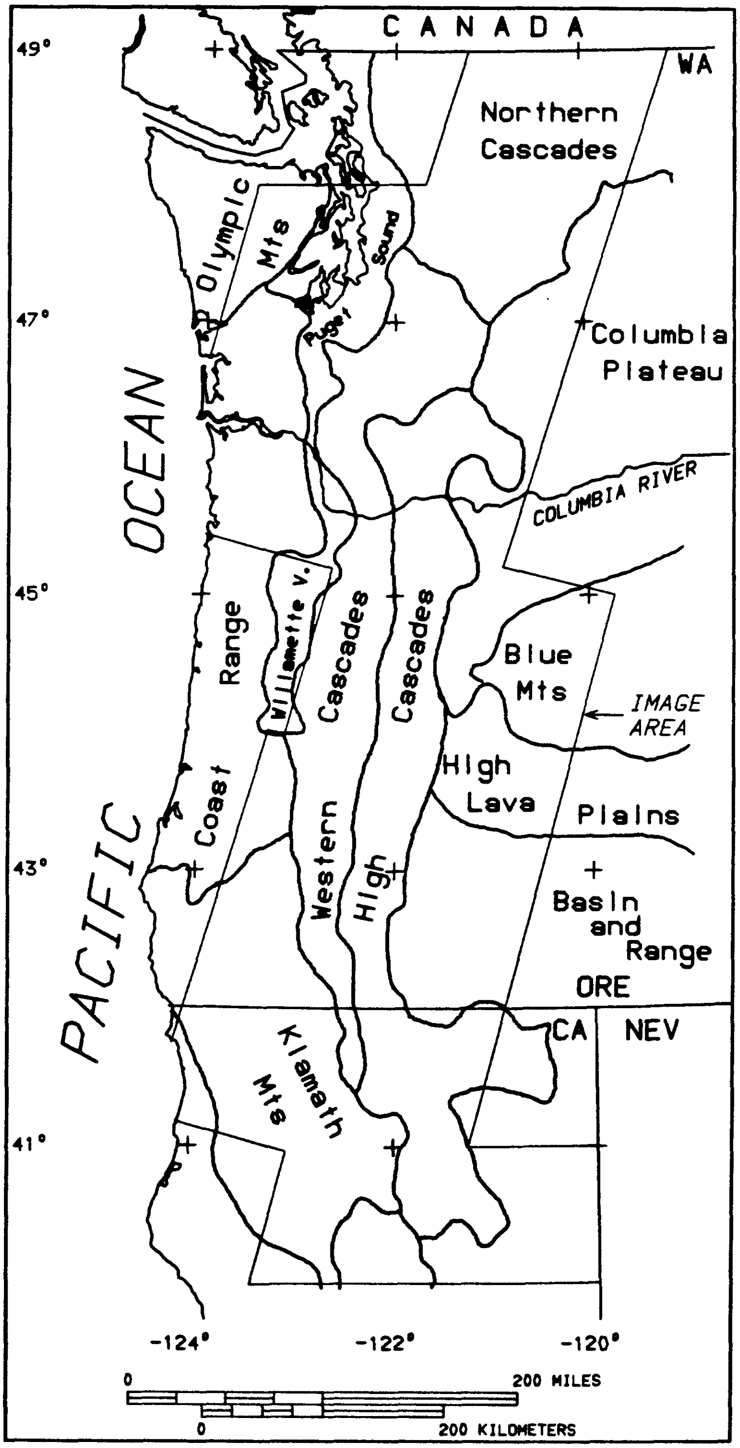

Figure 1. Index map of the Cascade Range region showing the major tectonic/ physiograpic provinces and the outline of the computer-enhanced Landsat MSS images used to map linear features.

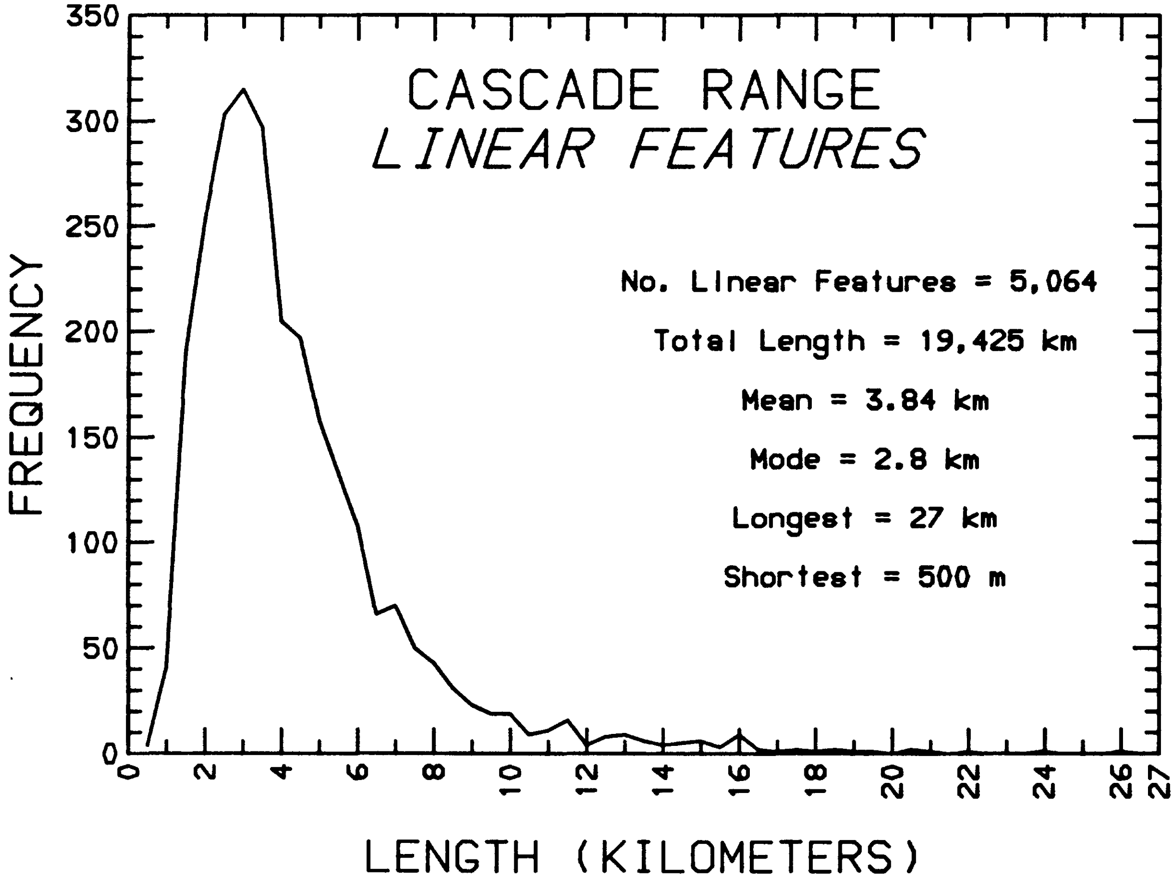

Figure 2. Length-frequency histogram of 5,064 linear features mapped from computer-enhanced Landsat MSS images of the Cascade Range region.

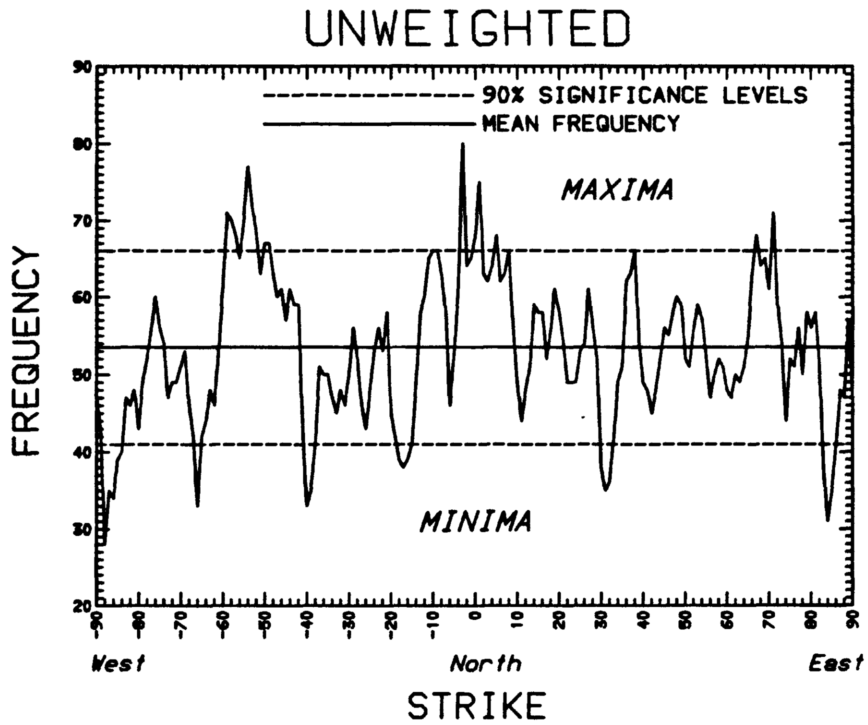

Figure 3. Unweighted strike-frequency histogram of linear features greater than 2.8 kilometers long.

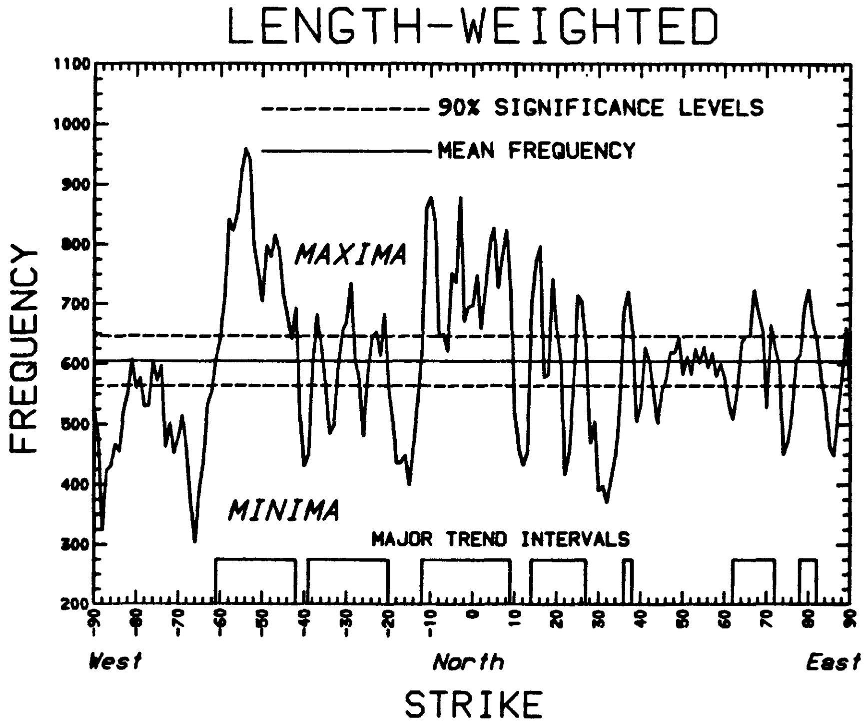

Figure 4. Length-weighted strike-frequency histogram of linear features greater than 2.8 kilometers long, showing the important trend intervals selected by visual examination.

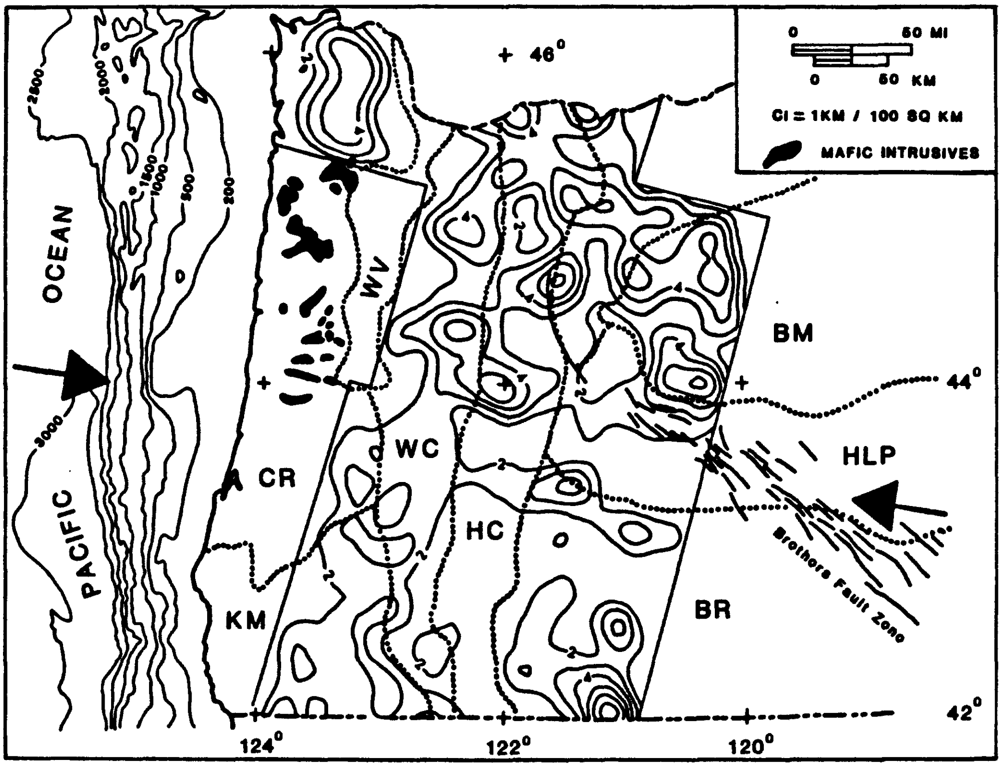

Figure 5. Sketch map of central and western Oregon showing the concentration of all linear features and selected geologic features and physiographic/tectonic provinces (after King and Beikman, 1974). Large arrows mark the structural and volcanic trend of the High Lava Plains and its projection west-northwestward across the Cascade Range to the continental shelf. A change in linear feature concentrations occurs across this trend. HLP, High Lava Plains; BM, Blue Mountains; BR, Basin and Range; HC, High Cascades; WC, Western Cascades; WV, Willamette Valley; KM, Klamath Mountains; CR, Coast Range.

Appendix A

Maps of Linear Features in Selected Trend Intervals

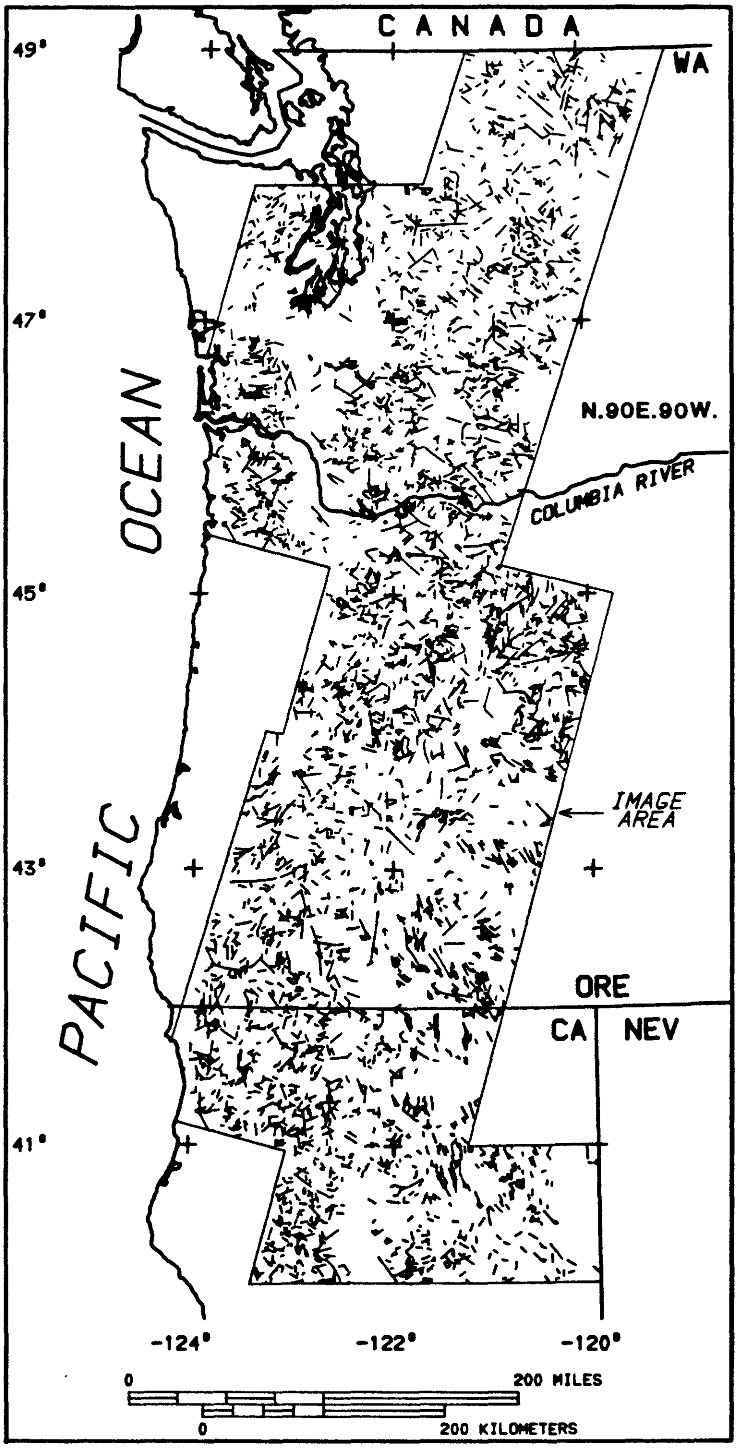

Figure A1. Map of 5,064 linear features interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

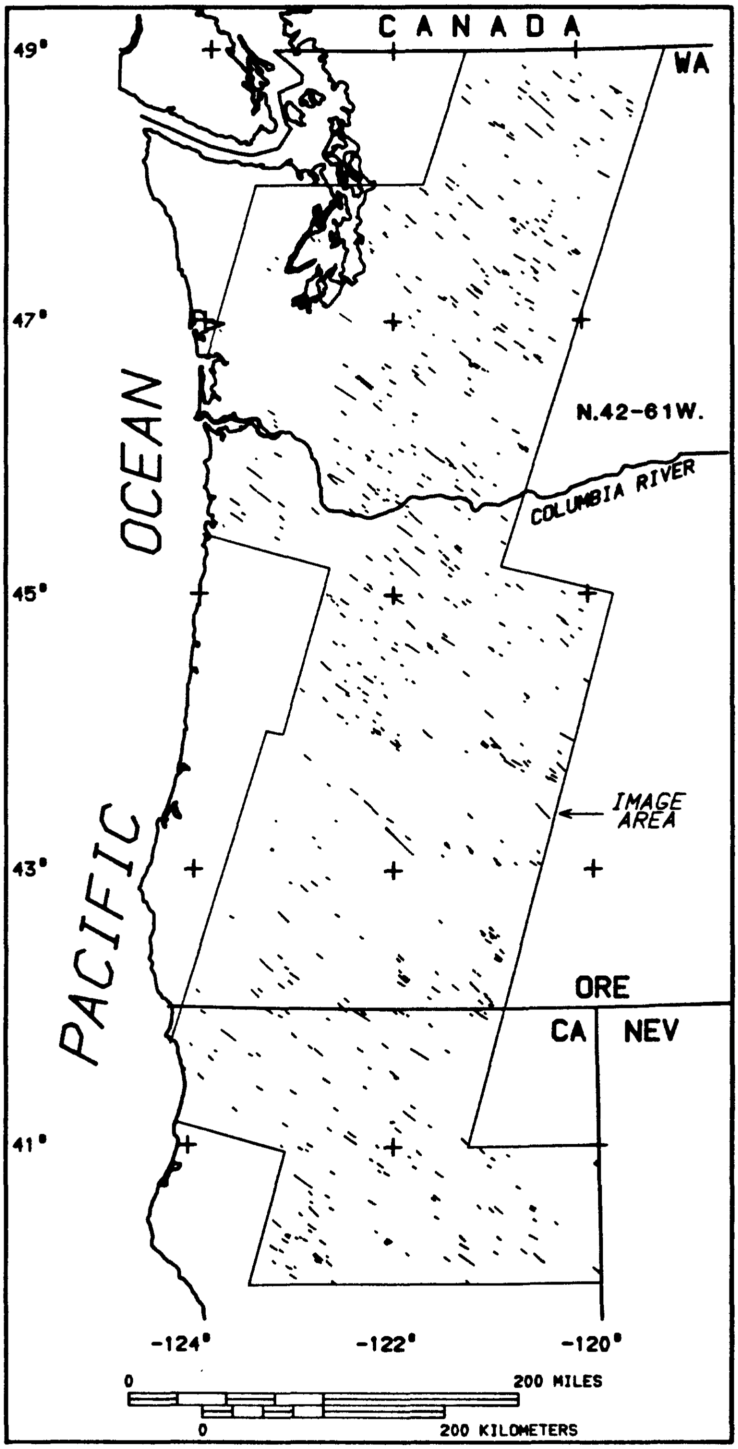

Figure A2. Map of linear features trending N.42°-61°W. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

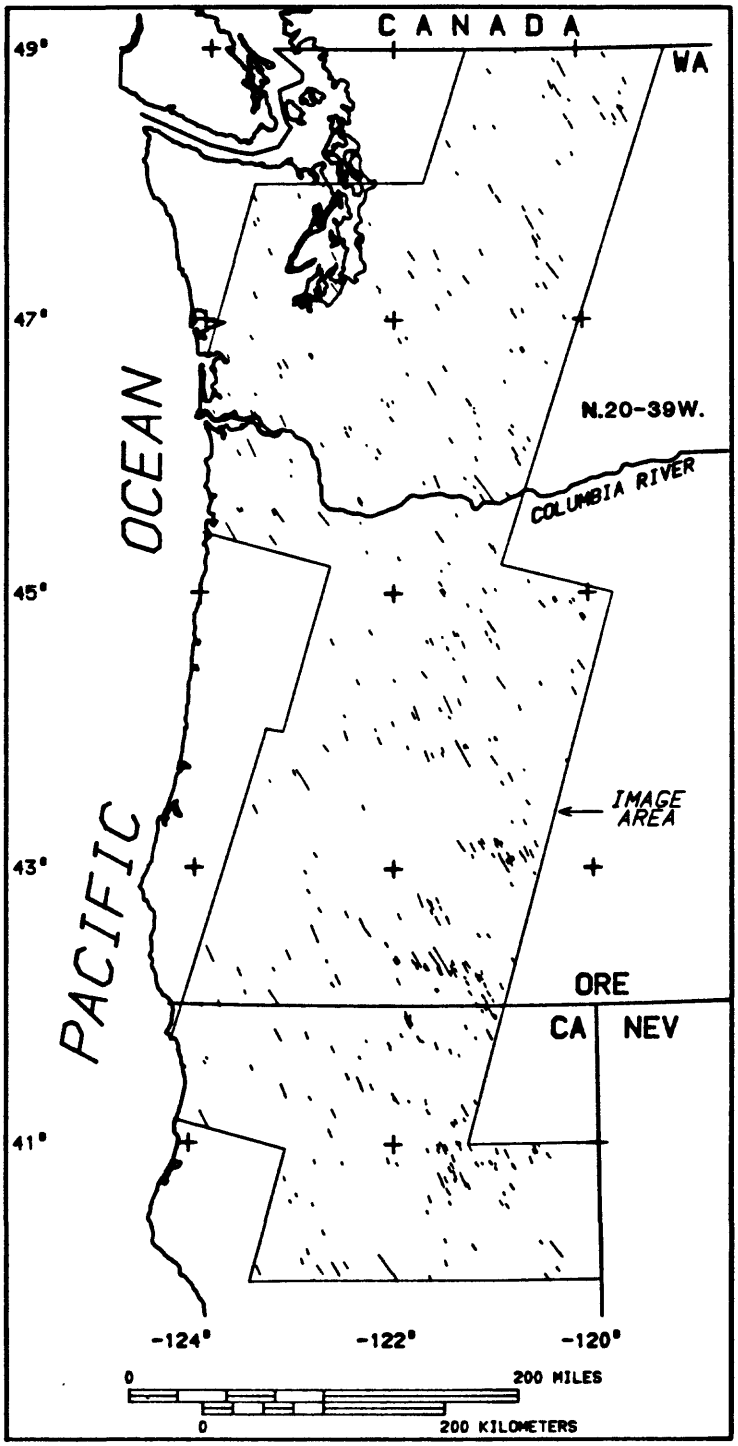

Figure A3. Map of linear features trending N.20°-39°W. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

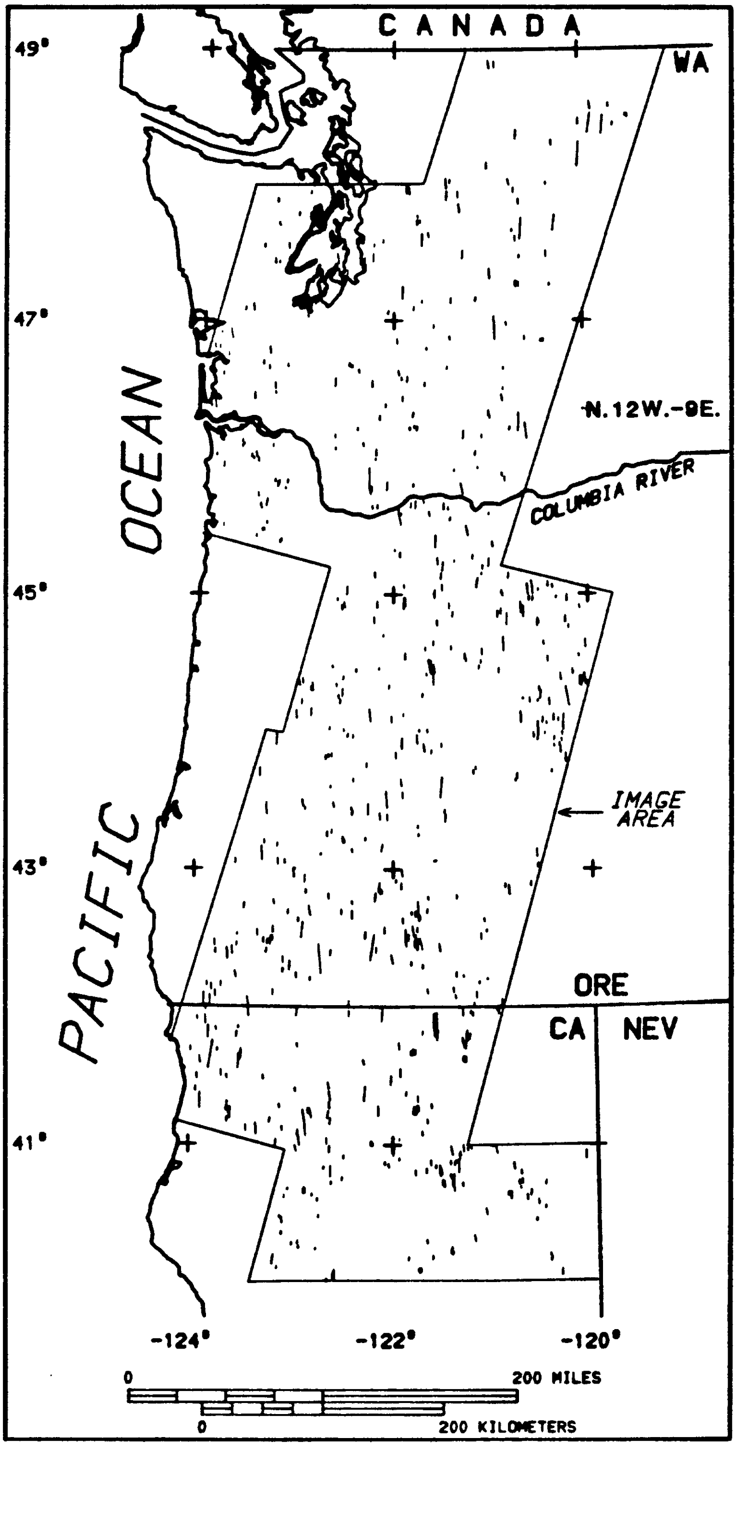

Figure A4. Map of linear features trending N.9°E.-12°W. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

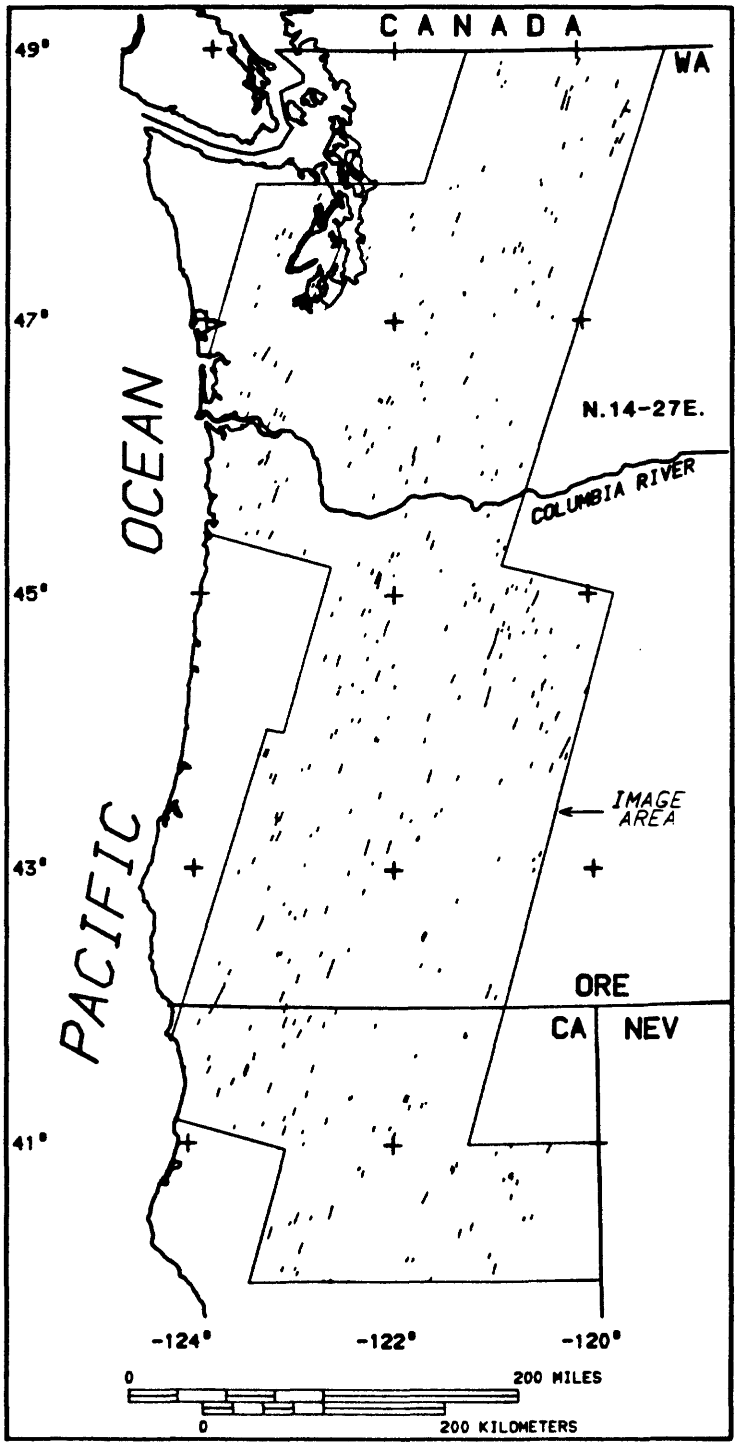

Figure A5. Map of linear features trending N.14°-27°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

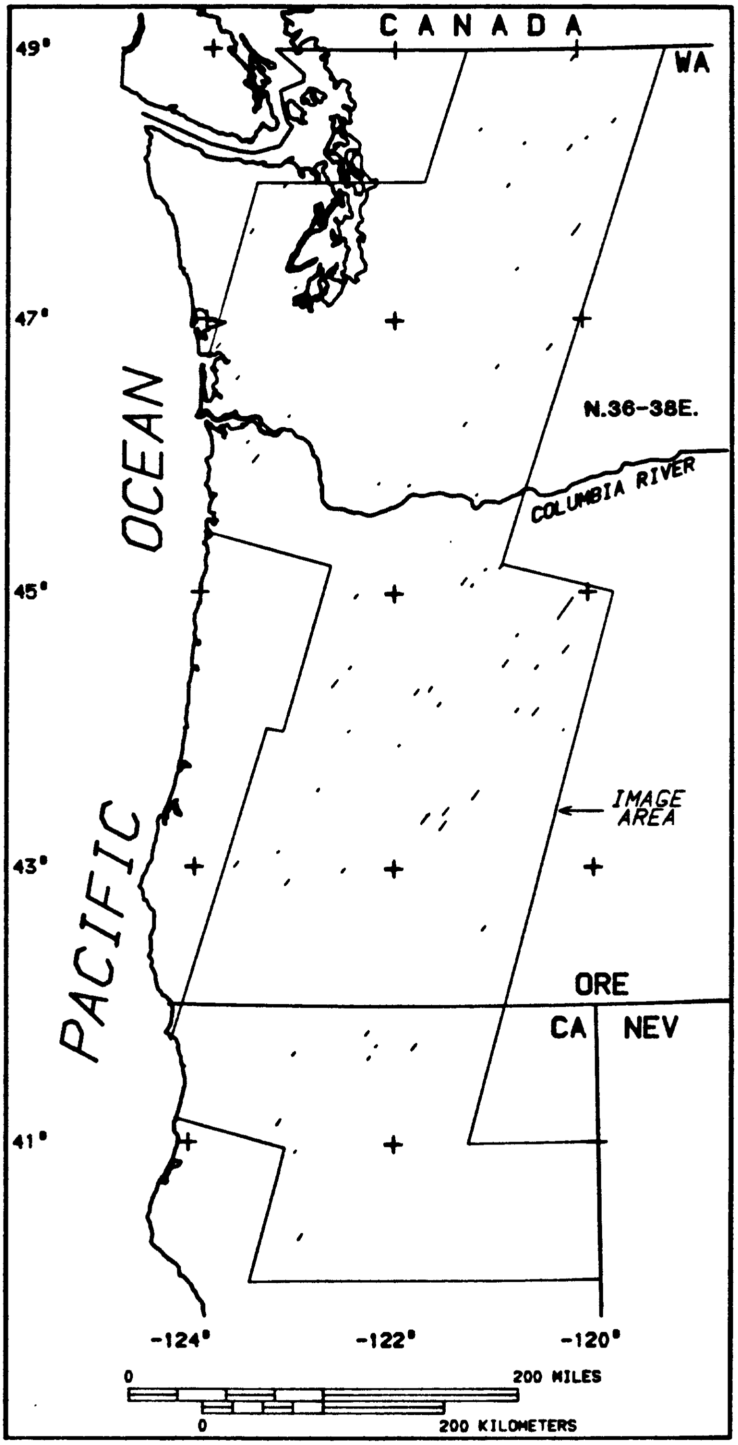

Figure A6. Map of linear features trending N.36°-38°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

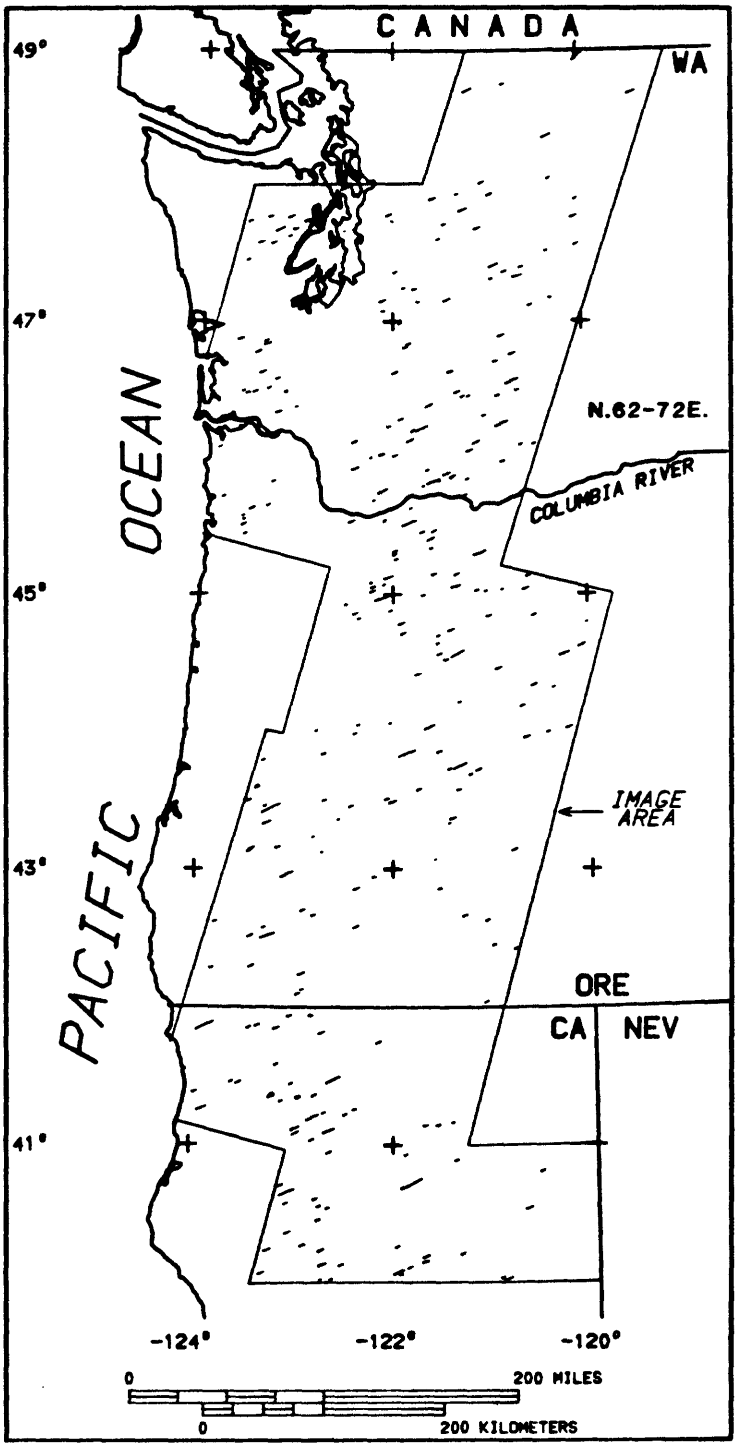

Figure A7. Map of linear features trending N.62°-72°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

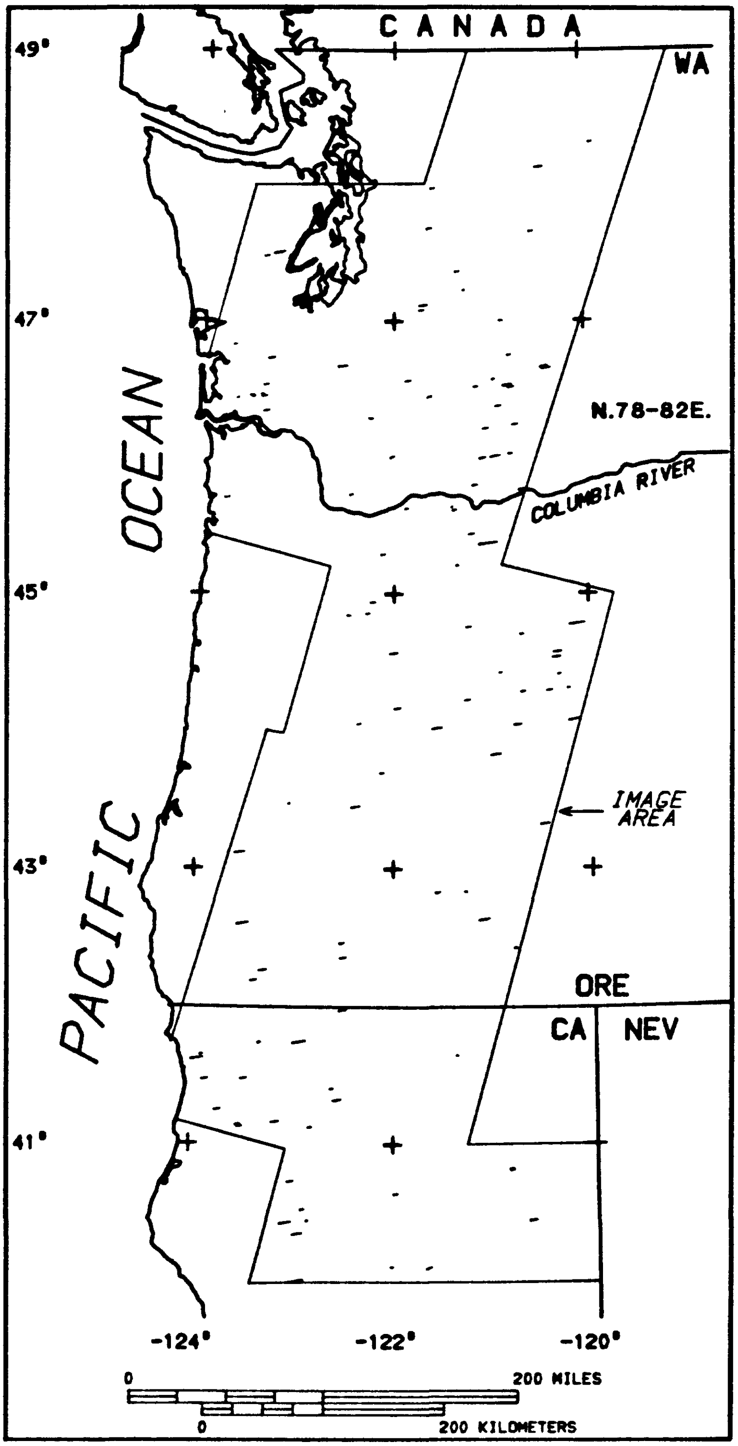

Figure A8. Map of linear features trending N.78°-82°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

Appendix B

Contour Maps of Concentrations of Linear Features in Trend Intervals Selected from Strike-Frequency Analysis

The contours on these maps are length of linear features (in kilometers) measured in a 55 x 55 kilometer cell moved across the linear features map in 5 kilometer increments.

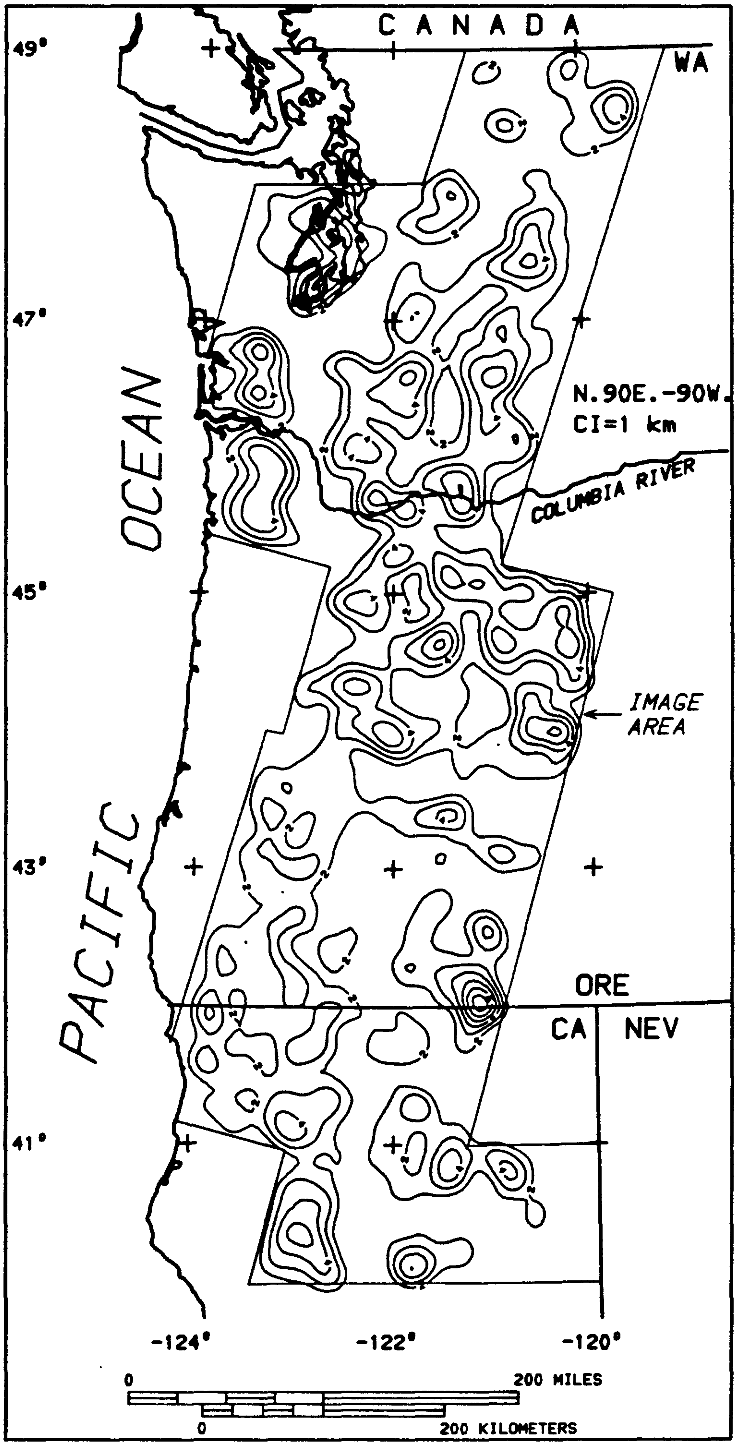

Figure B1. Concentration map of 5,064 linear features interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

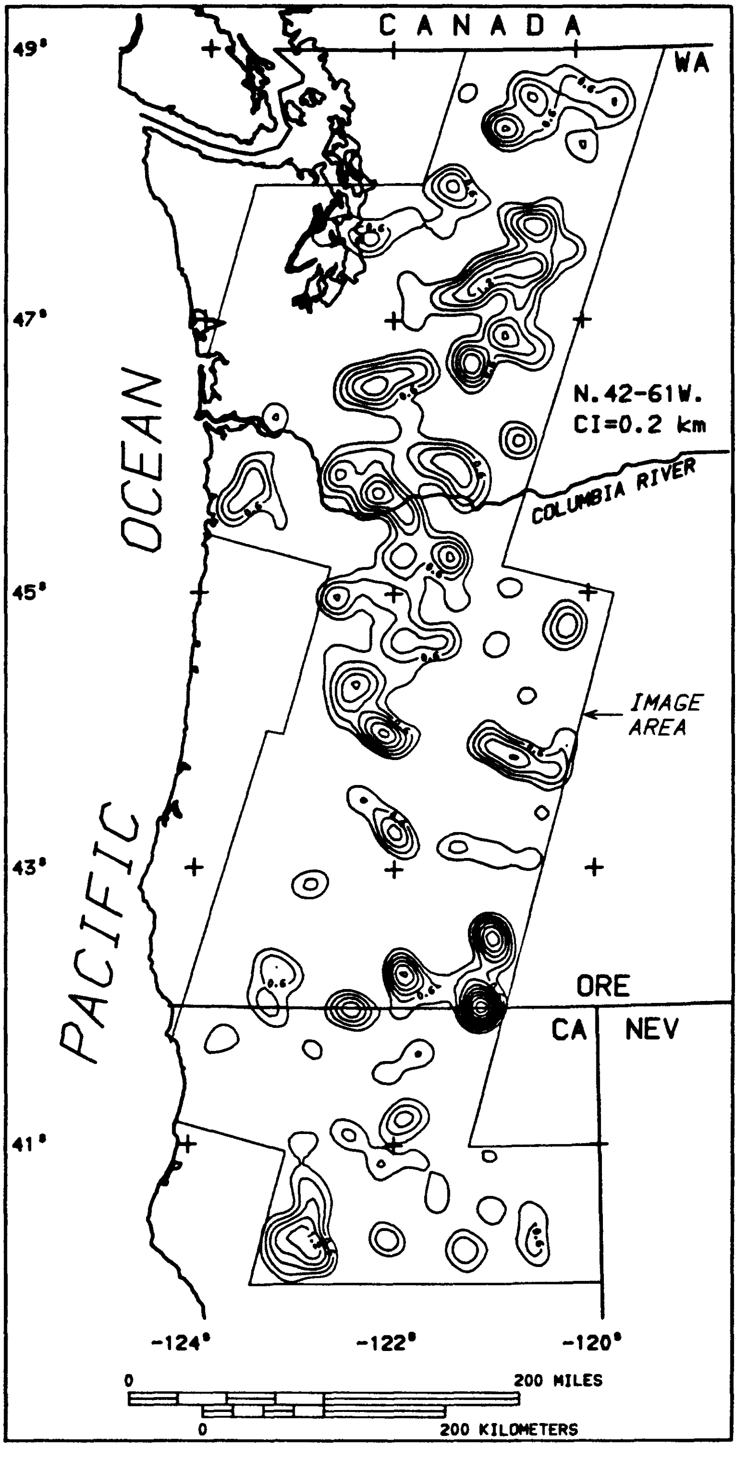

Figure B2. Concentration map of linear features trending N.42°-61°W. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

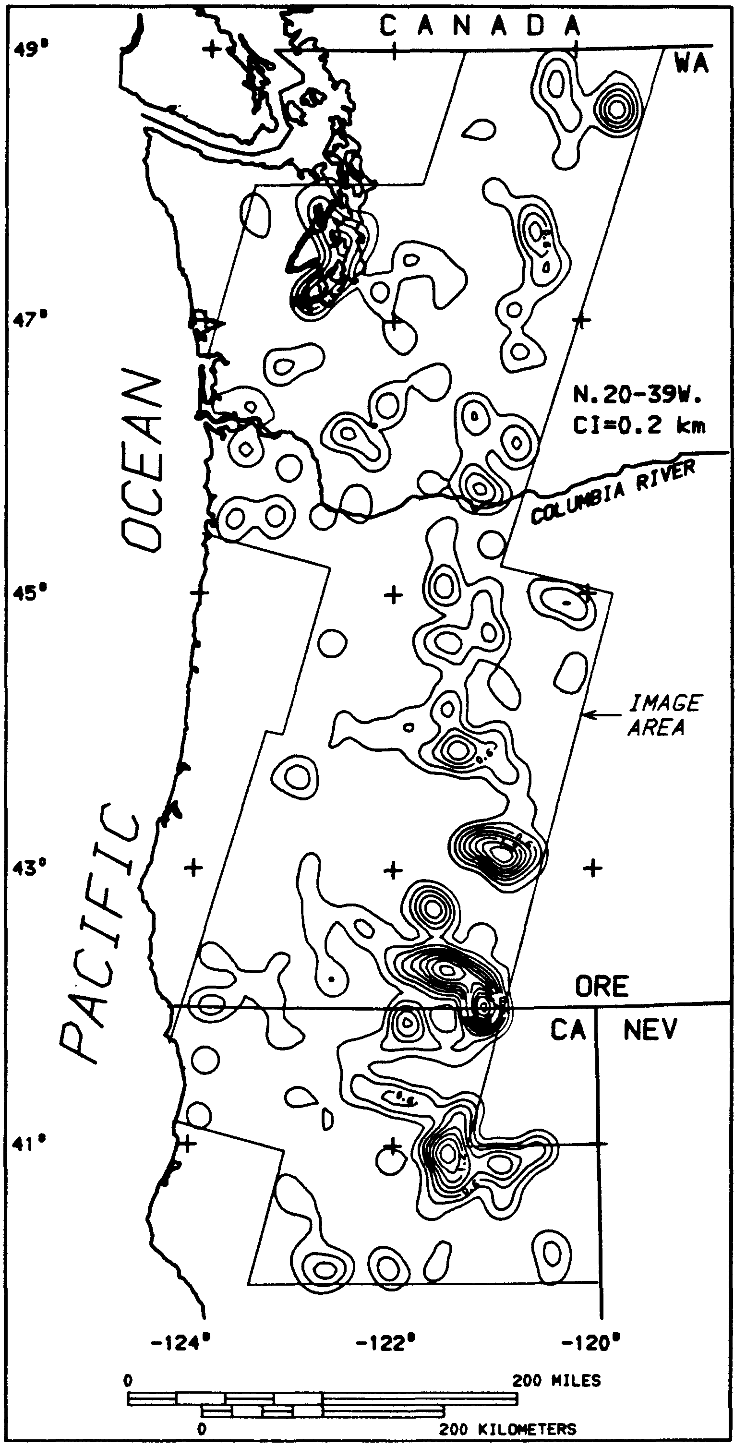

Figure B3. Concentration map of linear features trending N.20°-39°W. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

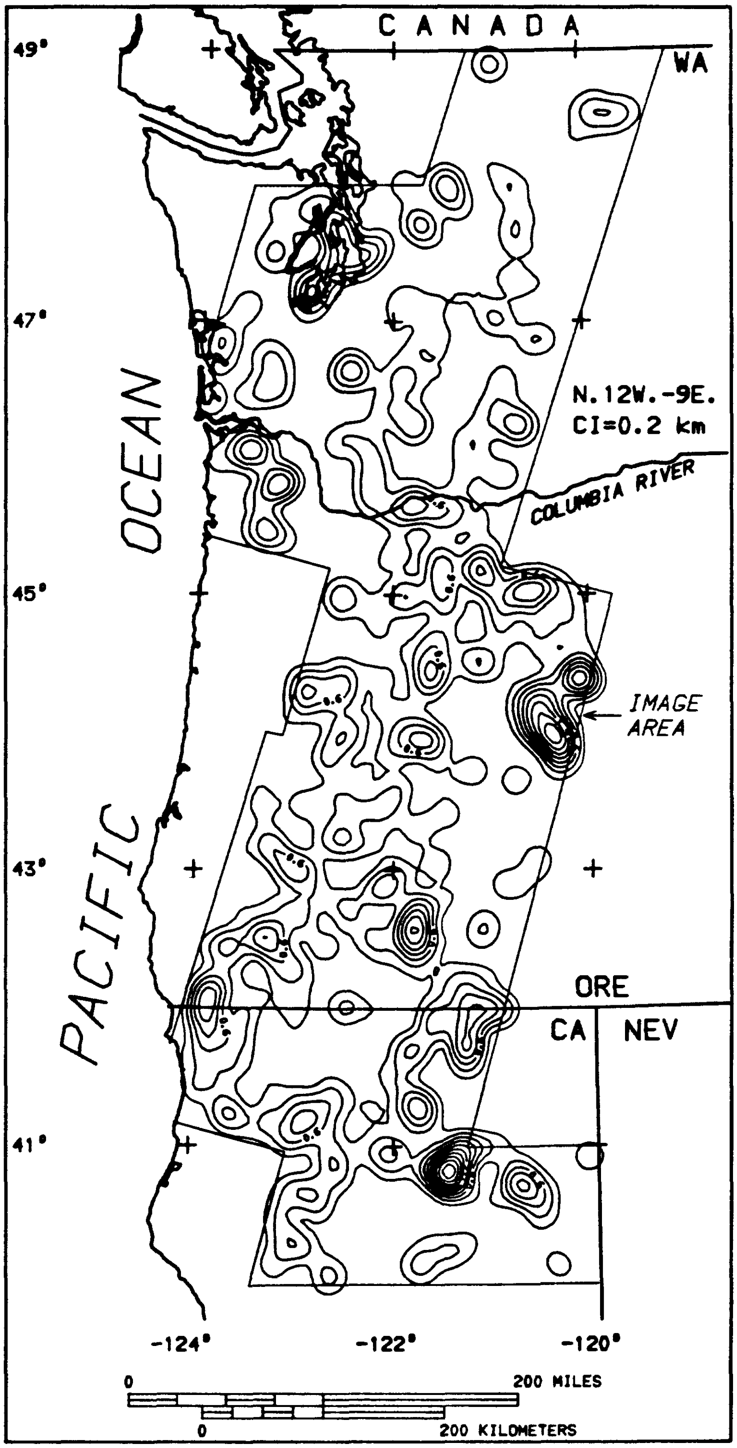

Figure B4. Concentration map linear features trending N.9°E.-12°W. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

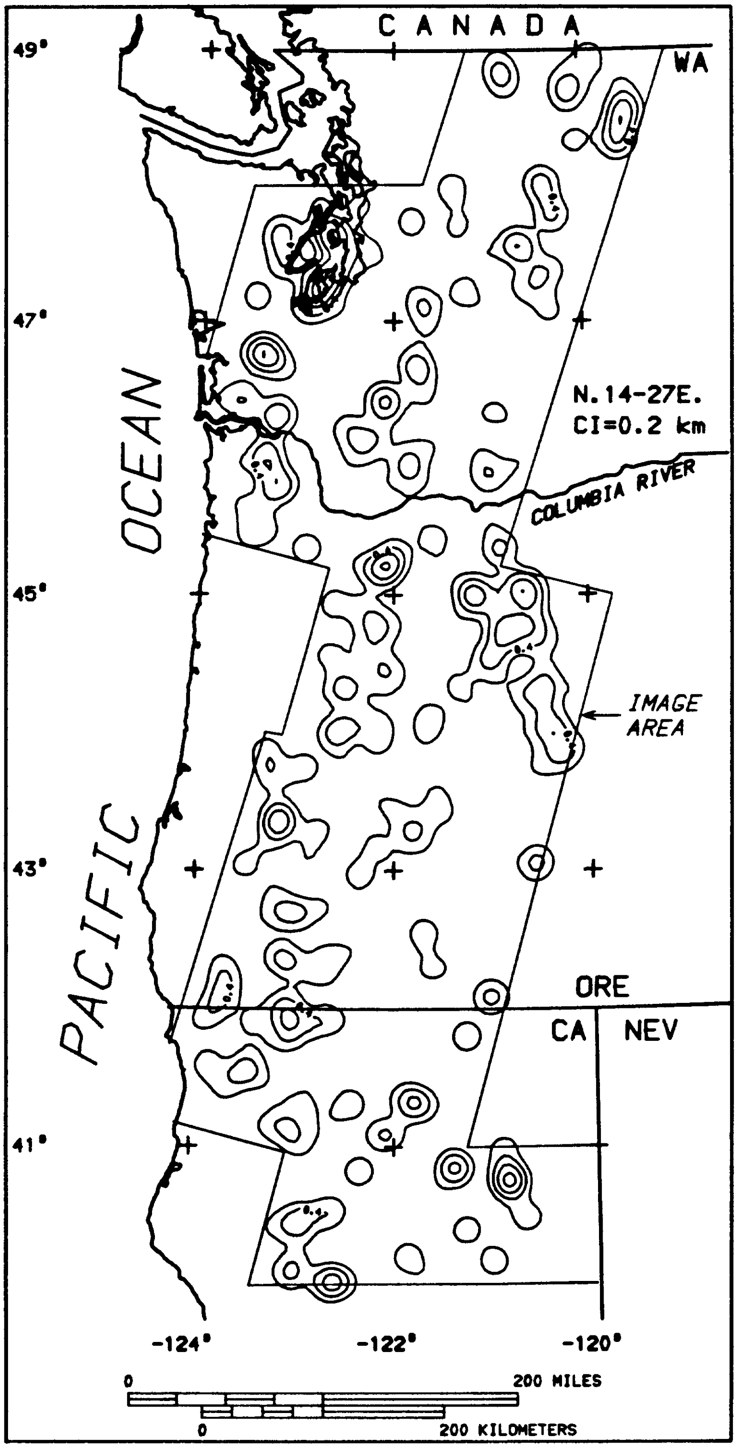

Figure B5. Concentration map of linear features trending N.14°-27°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

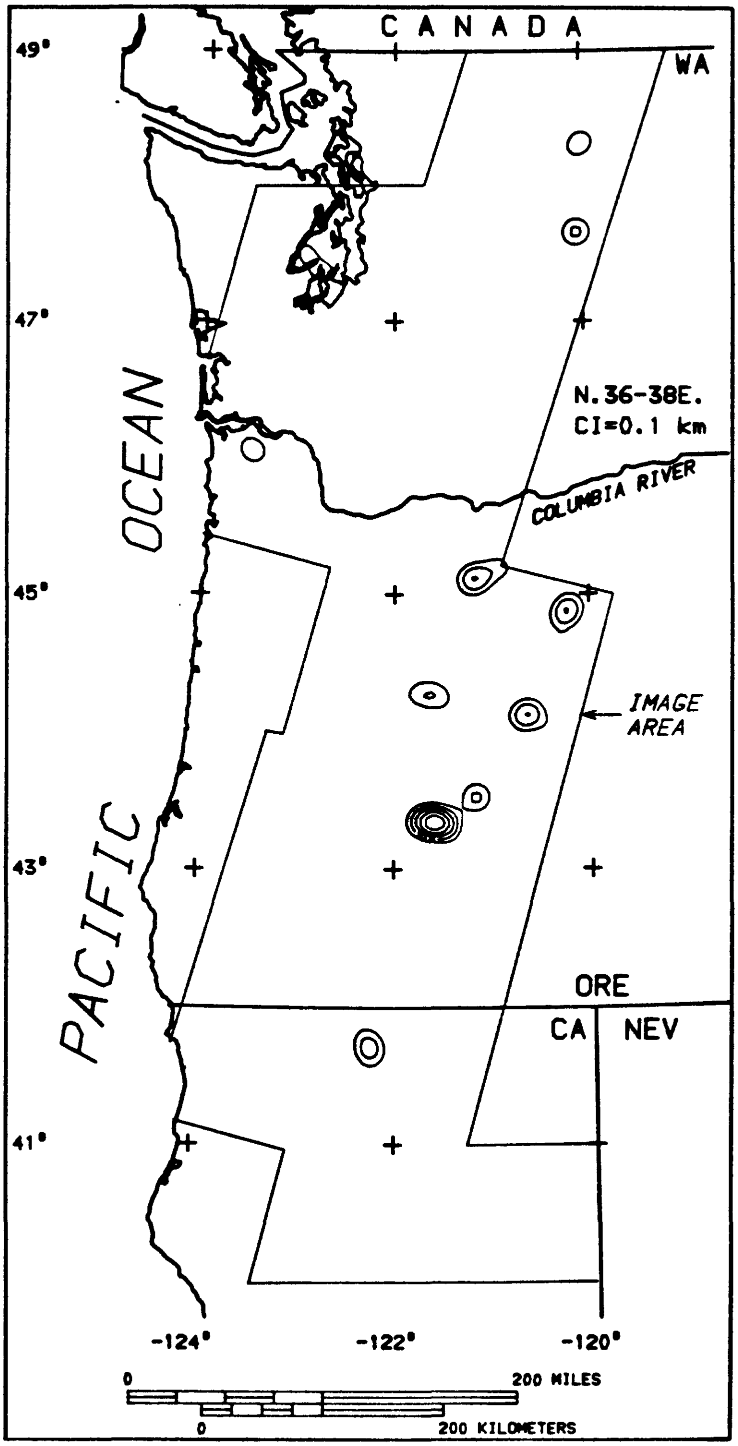

Figure B6. Concentration map of linear features trending N.36°-38°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

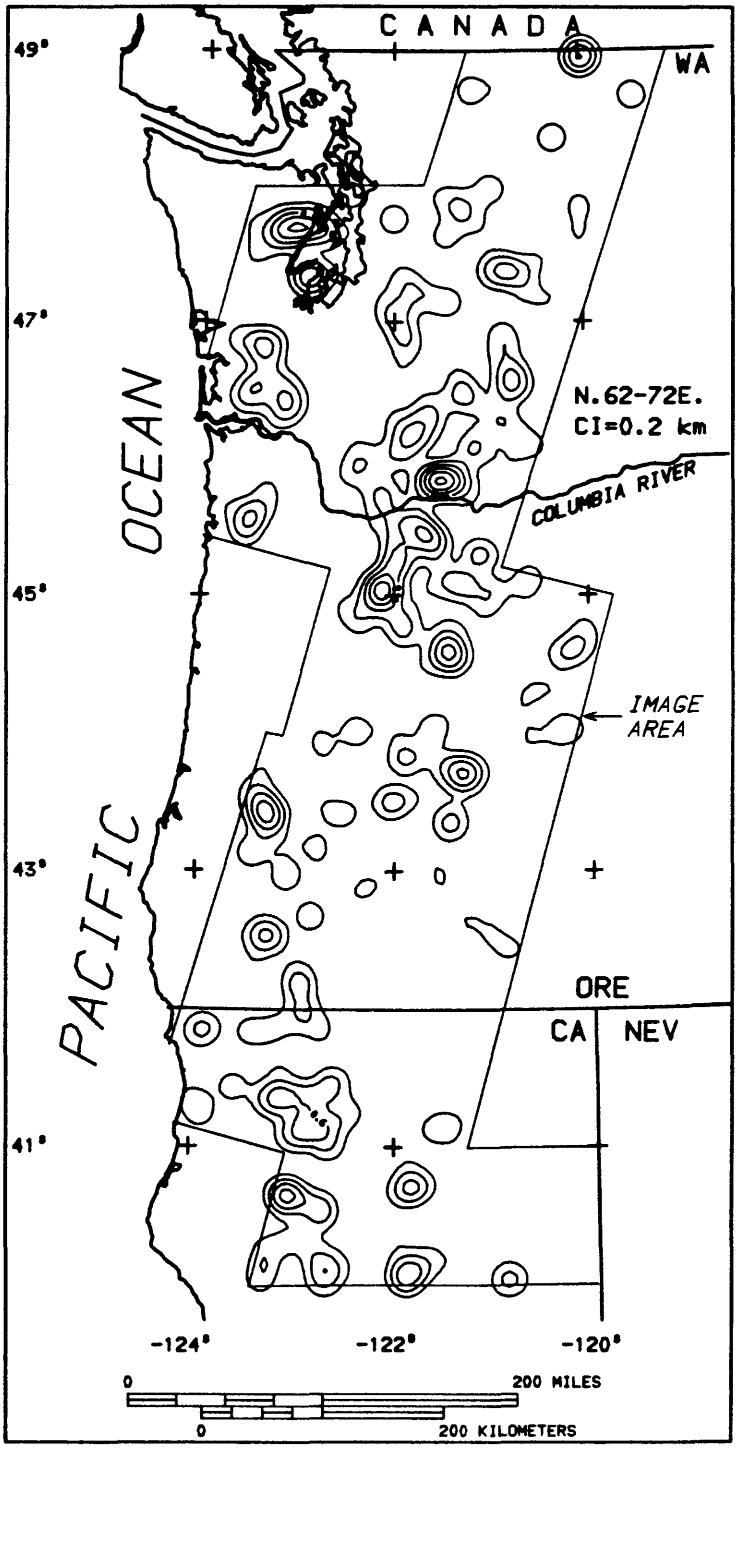

Figure B7. Concentration map of linear features trending N.62°-72°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.

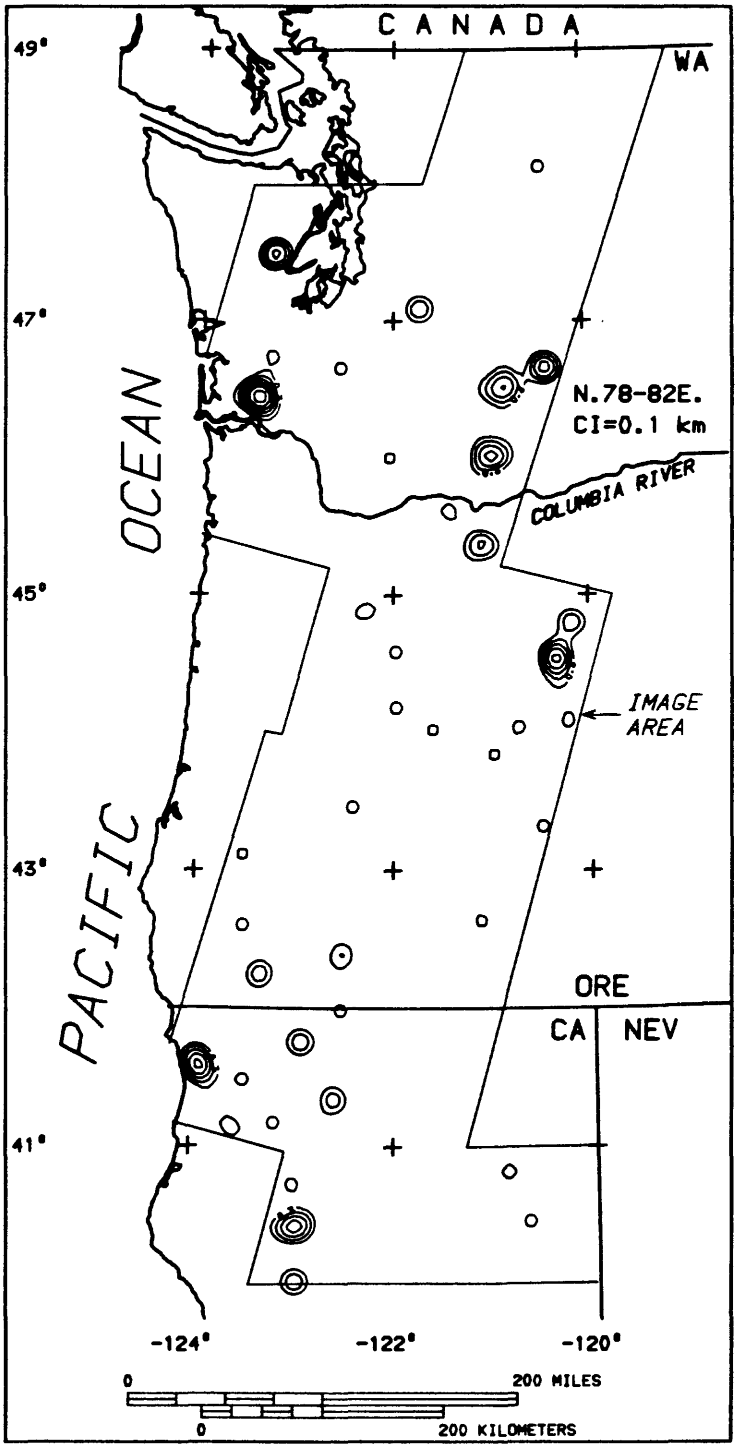

Figure B8. Concentration map of linear features trending N.78°-82°E. interpreted from computer-enhanced Landsat MSS images of the Cascade Range region.