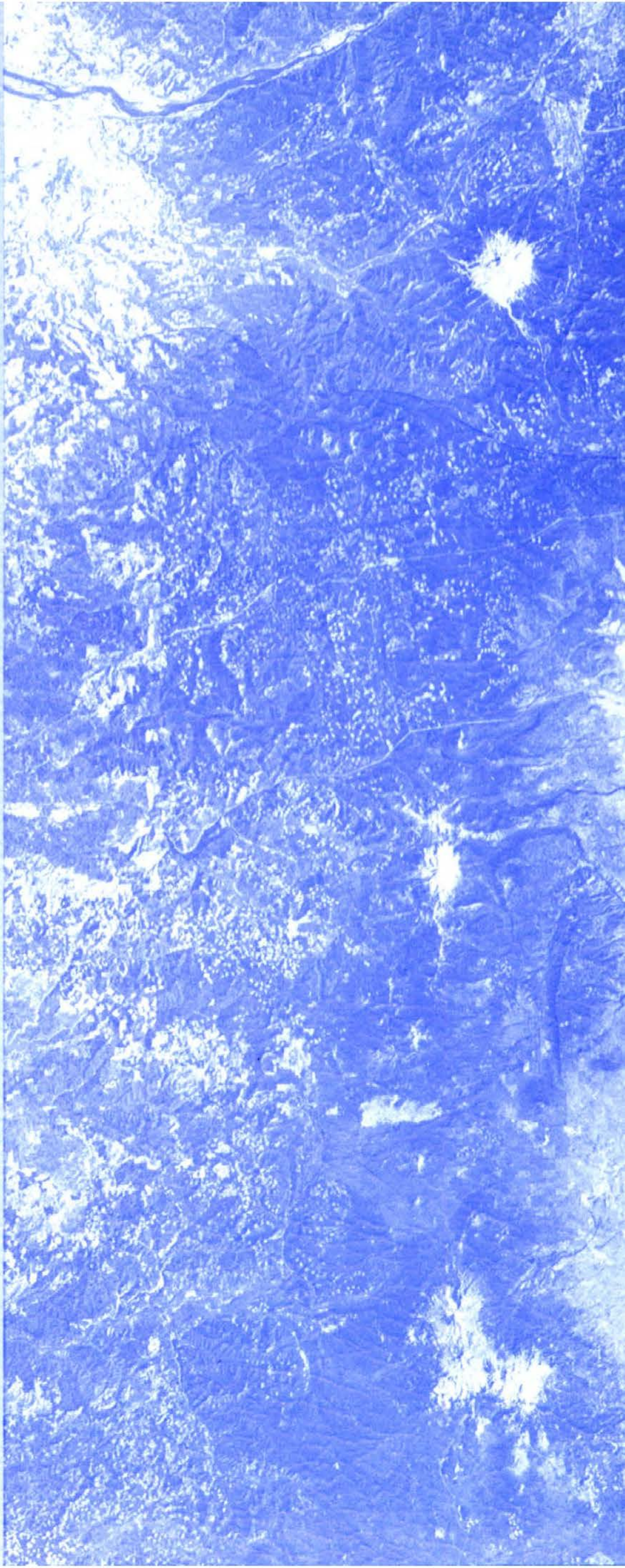
SPECIAL PAPER 12

GEOLOGICAL LINEARS OF THE NORTHERN PART OF THE CASCADE RANGE, OREGON

1980



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
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SPECIAL PAPER 12

GEOLOGICAL LINEARS OF THE NORTHERN PART OF THE CASCADE RANGE, OREGON

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MOSCOW, IDAHO

1980

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ILLUSTRATIONS

INTRODUCTION

Purpose and Scope

This photo and imagery interpretation study was undertaken by Geoscience Research Consultants for the Oregon Department of Geology and Mineral Industries to develop geologic linears maps for the Cascade Range of central and northern Oregon. The primary objective of this work is to provide linears maps which may be used to identify unmapped faults, to allow extension of known faults and to define structural patterns in the vicinity of the Cascade Range. The scope of the study is confined primarily to identifying geologic linears within the area and to presenting their location and orientation in a systematic format. Preliminary interpretive observations are included as a basis for further discussion.

Acknowledgments

The writers wish to recognize the cooperation shown by personnel of the Oregon Department of Geology and Mineral Industries and their expeditious handling of requests and inquiries. We thank C. Scott Kimball for his timely assistance during our use of photo interpretive facilities and film library at Battelle Pacific Northwest Laboratories, Richland, Washington, while making supplemental study of selected images. The comments and technical assistance provided by William B. Hall, Director, Geophotography and Remote Sensing Center of the University of Idaho, are also greatly appreciated as is the cartographic and compilation support provided by David C. Kachek of the Department of Geology at the University of Idaho.

Program Summary

This linears study is based on visual examination of photos and images from three principal data sources. These are high-altitude (U-2) infrared film positive prints (1:130,000), side-looking airborne radar (SLAR) mosaics (1:250,000) and orbital (LANDSAT) multispectral scanner film positive imagery (1:1,000,000). Identification of linears was through stereoscopic study of photos and direct annotation of non-stereoscopic renditions. Linears data are presented in map format and summarized with rose diagrams.

Base map scale for final map compilation of U-2 and SLAR linears is 1:250,000; LANDSAT data are plotted at 1:1,000,000 scale and include annotations for the region surrounding the area of principal study. U-2, SLAR and LANDSAT map compilations are carried as Plates I, II and III, respectively. Each of Plates I and II has been split into southern and northern halves for cartographic and printing purposes; the southern portions are denoted "A" (Plate I-A and Plate II-A) and the northern portions are "B" (Plate I-B and Plate II-B).

The general criteria and procedures utilized for recognizing and categorizing linears is discussed briefly in the text. This is followed by comments on the implications of possible regional structural and tectonic patterns.

The linears study of the Cascade Range of Oregon was initiated in April 1980; this report was submitted in July 1980.

General Setting

Location

The Cascade Range study area is located in west-central Oregon (Figure 1). It includes the volcanic peaks of the High Cascades on the east and the more eroded uplands of the Western Cascades on the west.

The area of study is rectangular in general configuration with the elongate direction north-south. The area covers approximately 8,500 square miles (21,500 sq km). The western boundary is 122° 45'W longitude; the eastern boundary is 121° 30'W longitude. The area extends northward to the state boundary along the Columbia River near 45° 45'N latitude. The southern boundary is 43° 30'N latitude. As reference points, Portland is located in the northwestern corner of the area with the community of Hood River in the northeastern. The western margin lies just to the east of the Willamette Valley population corridor which includes the cities of Salem, Albany and Eugene. The eastern margin is located a few miles to the west of the municipalities of The Dalles and Bend. Crater Lake is situated about 30 miles south of the southern boundary.

Few large communities lie within the study area. It is more noted for such volcanic peaks as Mount Hood, Mount Jefferson and the Three Sisters of the High Cascades. Streams heading in the High Cascades and draining westward through the Western Cascades include the Clackamas, Santiam and McKenzie; these are tributaries of the Willamette River. Streams draining eastward from the High Cascades toward the Columbia Plateau are upper-elevation tributaries of the Deschutes River.

The relatively rural setting of the area has reduced the number of artifacts and cultural features which commonly interfere with linears mapping. However, the dense vegetation cover in many upland areas, together with scars of timber clearcutting, appears to have obscured to some degree the geologic linear features in these areas.

Geology

The Cascade Range study area considered in this report lies almost entirely within a volcanic province. Geologically (Figure 2), virtually all major rock units are eruptive in origin or have been derived from erosion of extrusive rocks. Where present, sedimentary units, including terrace deposits, are related to non-marine deposition of debris in or near the Willamette lowlands along the western border of the study area or are glacial deposits and alluvium related to Quaternary surficial processes (Qs).

Volcanic rocks of the Cascade Range are commonly separated into two groups; these are middle to upper Tertiary rocks of the Western Cascades and upper Tertiary to Quaternary rocks of the High Cascades. Oldest rocks in the area are Oligocene to Miocene tuffs, volcanic breccias, and associated water-laid units (Tomv). These are exposed near the margin of the Willamette Valley and in the cores of eroded, broad anticlines of the Western Cascades. Basalts of the Miocene Columbia River Basalt Group (Tmmb) form the next younger unit. These basalt flows are exposed at the foot of the eastern flank of the High Cascades near its juncture with the Columbia Plateau. They also are present in the north of the study area within the Columbia River Gorge and near the Willamette Valley in the Portland-Salem area. The main body of the Western Cascades consists principally of Miocene andesite flows, breccias and tuffs and associated basalt flows (Tmuab). The basalt flows are localized near the Willamette Valley in the Eugene area. The High Cascades are floored by Pliocene to Pleistocene basalt, andesite and pyroclastic units (Tpb and TQv). Generally these are strato-volcanic in disposition (Christiansen and Lipman, 1972) with modern, north-south aligned andesitic and basaltic volcanic cones (Qab) making up the backbone of the trend. As observed by McBirney (1978), a principal association of the Cascade Range volcanic province has been a marked narrowing of the

Figure 1.

Location map of the Cascade Range area

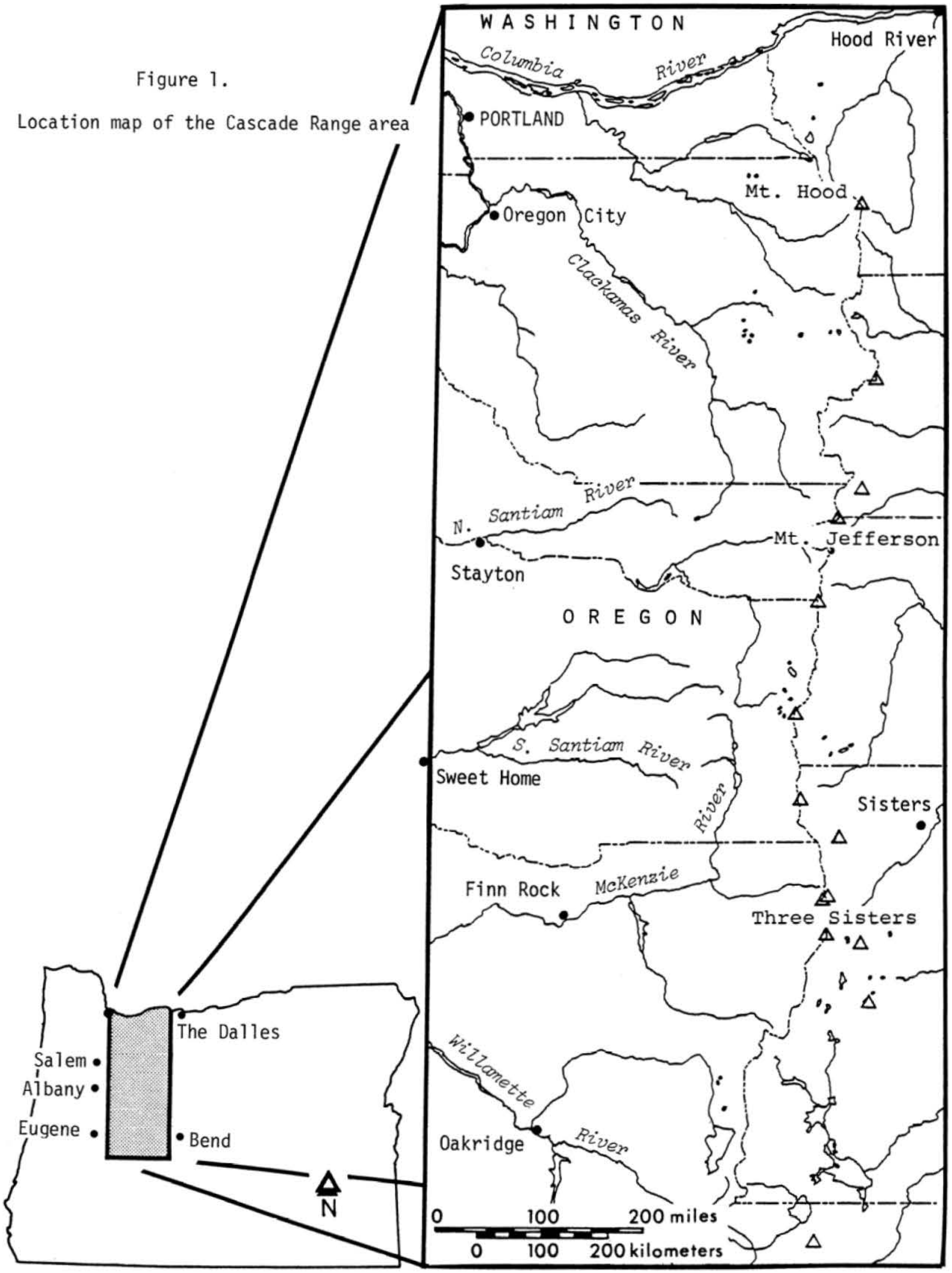


Figure 2.

Generalized geologic map

SEDIMENTARY UNITS

Qs — Quaternary alluvial, glacial and non-marine terrace deposits

VOLCANIC UNITS

Qa / Qb — Quaternary andesite (a)
Quaternary basalt (b)

TQv — Pliocene to Pleistocene andesite and basalt

Tpb — Pliocene basalt

Tmua / Tmub — Upper Miocene andesite (a)
Upper Miocene basalt (b)

Tmmb — Middle Miocene basalt

Tomv — Oligocene to Miocene flow and pyroclastic units

STRUCTURE

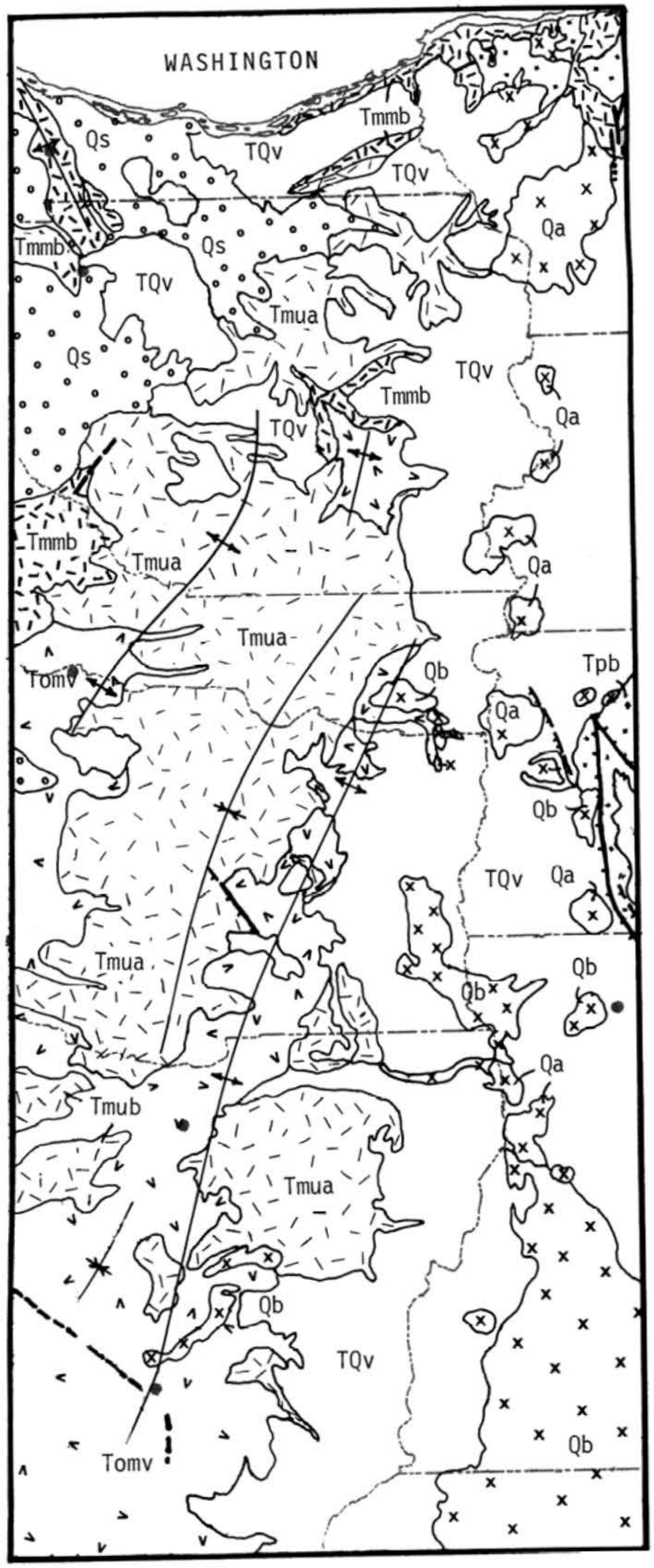
Anticline

Syncline

Fault

solid line--mapped
dashed line--inferred
dotted line--covered
bars on downthrown side

(after Peck, 1961)



focus of volcanism to form the present-day well-defined chain of composite cones along its entire length. The High Cascades, as exemplified by Mount St. Helens to the north in Washington, represent the most recent calc-alkaline volcanic activity in the United States. Paleomagnetic data suggest that most, if not all, of the major volcanic structures were formed by eruptions which occurred during the present polarity epoch.

Major faults and tight folds are relatively unmapped in the study area. A few broad anticlines and synclines are present in the Western Cascades; these structures predate the extrusive events of the High Cascades. Normal faults are mapped in regional perspective at scattered localities along the trend of the High Cascades and in a few areas of the Western Cascades (Figure 2).

Terminology and Definitions

Terminology used in this report is based on practices established by previous workers and on adaptations necessary to adjust for conditions in the study area and the nature of data sources. Conventional terminology has been applied where practical. For background, a brief summary of the development of selected terms follows; of particular concern is the contrast of use between the terms lineament and linear. For more detailed discussion the reader is referred to concurrent work (Venkatakrishnan and others, 1980).

Lineaments

The term lineament was used by Lapworth (1892) and Hobbs (1912) to denote persistent landscape lines, topographic breaks or surficial expressions which reflect large lineal features in subsurface rock. These lineaments typically were considered regional in extent, were recognizable from field observations or relief depictions, and were categorized as physiographic or geomorphic features (Raisz, 1945). As the structural significance of region-wide lineaments became apparent, the term also was applied to elongate zones of lineal structural features. The major lineaments were interpreted in some cases to reflect continental-scale "regmatic" fracture systems.

Wrench or shear faults were the most common interpretation given to lineaments (Moody and Hill, 1956; Maxwell and Wise, 1958;and Carey, 1958). A pattern of worldwide tectonics has been proposed by many recent investigators for the distribution of numerous recognized lineaments (Gay, 1972; Wilcox and others, 1973; Moody, 1974;and Hodgson, 1974). However, not all interpretive thought on lineaments is unified; an association between lineaments and the effects of the earth's rotation has been proposed as one alternative to wrench-fault tectonics (Rance, 1967;and Shul'ts, 1971). Within the study area one hypothesized lineament or regional fault zone has been described by Lawrence (1976). It is the Eugene-Denio zone extending southeasterly from Eugene across the southwestern portion of the linears study area. Lawrence also described the southeasterly trending Brothers strike-slip fault zone to the east of the study area; this he considers to terminate westerly in the Three Sisters area of the High Cascades.

Linears

As photographic and imagery platforms and capabilities expanded rapidly after World War II, so did the detail and perspective in which interpreters could work. This has led, in part, to more precise and systematic work with local lineal features. These features, termed linears, generally are identified from remotely sensed imagery and generally are rather abrupt, localized or segmented structurally controlled lineations in the crust.

In most interpretive studies, linears are considered to represent "fractures". That context is applied in this study with the term "geologic linears" including any line or zone of weakness in the rocks of the crust which is expressed surficially as recognizable from remotely sensed imagery. These fractures may be faults and have had relative movement along them or they may represent joints, partings, stress-relief planes or incipient shears with very little movement involved.

The terms used in this report which apply to linears are summarized in Figure 3. Usage follows parameters set by O'Leary and others (1976). Linears mapped for this report are based principally on the following identifying characteristics or on combinations of them.

- Landform expression--as elongate ridges, valleys, scarps and breaks in slope.
- Tonal change--as lineal dark or light tonal contacts, contrasts or boundaries.
- Pattern or texture change--as systematic interruptions or shifts in character.
- Vegetation break--as natural boundaries of plant types, densities or communities.
- Drainage pattern expression--as persistence of alignments or as straight segments of otherwise irregular streams.

In addition, linear recognition and extension incorporates such variables as length, azimuth, position, spatial form, frequency, group relationship and implication of relative movement or displacement.

As observed previously, the geologic linears mapped for this study have been determined by visual examination of photos, mosaics and images. Therefore, interpretive or subjective determinations are involved. To qualify the subjectivity of the mapping, three levels of annotation are depicted on the compilations.

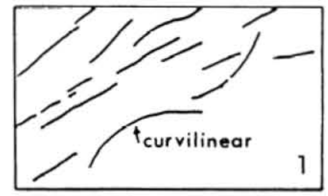
- Strong linear expression for long, pronounced features--annotated as solid lines.
- En-echelon linear expression for numerous aligned or slightly offset segments--annotated as dashed lines.
- Subtle linear expression for short features or tonal changes and probable extensions of more pronounced linears--annotated as dotted lines.

Non-fracture lineal features, such as eroded volcanic cones and plugs, have been annotated on compilation maps for reference purposes as have selected volcanic peaks and major geographic features.

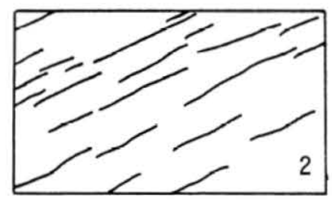
Figure 3.

Linears terminology

1. Linear--A fracture of any length or width in rocks. It may be masked or exposed but the term applies only to situations where there is evidence of structural control. The term is useful as it embraces faults, incipient shears and joints which have similar appearances on images. Rectilinears are straight or nearly so; curvilinears are arcuate or appear flexed in plan view.

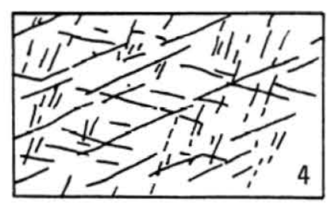


2. Linear Set--A series of parallel or subparallel linears as seen in plan or map view. It is a family relationship. Linears may be called close or wide to express their relative spacing.

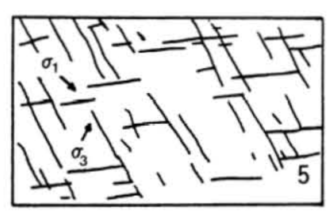


3. Systematic Linears--A group of linear sets in which the linears of one set may and typically do intersect linears of another set. These need not form conjugate sets. Linear Density--The number of linears, regardless of orientation, present in a unit area.

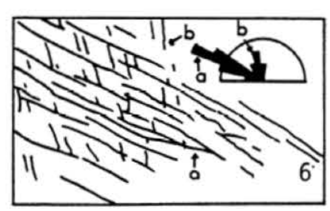
4. Linear Pattern--The spatial pattern formed by two or more sets of linears as seen in plan view.



5. Conjugate Sets--Any two sets of linears that are formed at the same time and by the same tectonic stresses.



6. Preferred Orientation--The greater prominence of one or more sets of linears within a pattern of a greater number of linear sets. Statistical methods can identify significant peaks within the parent population of linears.



LINEAR MAPPING

Procedures and Observations

As outlined in the INTRODUCTION, linears mapping in the Cascade Range of Oregon was based on visual study of three data sources--U-2, SLAR and LANDSAT. Coverage with these three sources was complete for the area (Figure 4); at least one rendition of each image source for any locale was available for comparative work with the other two. However, as discussed subsequently, much variation was found in resolution, contrast and density between individual prints from the same remote sensing source and among the three sources. Distortion also is marked in the SLAR mosaic. The quality of rendition of each source is summarized in Figure 5; imagery parameters are summarized in Table 1.

U-2 mapping

Approximately 140 high-altitude infrared 9" x 9" film positive prints (1:130,000) were studied for geologic linears (Figure 6). The general procedure was to view back-lighted film positive prints in stereo pairs using a rack-mounted Leitz binocular mirror stereoscope with x3 magnification. Linear features were traced directly on a mylar overlay registered to one of the pairs. Subsequently, the mylar overlay registered to the alternate photo received the same annotation step when it was studied in stereo with the next adjoining print. However, stereo pairs were often selected randomly so that previously mapped linears were not subconsciously searched for or projected onto adjoining frames.

At appropriate stages in the study selected U-2 photos were re-examined and annotated using a second registered overlay. This second overlay was then compared with the first to assure that a satisfactory level of reliability and consistency in linears identification was being obtained.

Upon completion of U-2 linears annotation, the mylar overlays were reduced to 1:250,000 scale for transfer to a common base map either by zoom transfer scope techniques or by scale reduction of linears already transferred to a 1:130,000 scale base map. Final compilation is depicted on Plates I-A and I-B.

Following compilation of geologic linears at final scale, rose diagrams were prepared for a semi-quantitative analysis of the linears data and to help in making preliminary observations about linears recognized from different data sources. These diagrams also were considered when making preliminary observations about the tectonic setting of the area as interpreted from linears-pattern development. For the preparation of rose diagrams the study area was arbitrarily divided into square cells with a land grid 21 miles (34 km) on a side (Figure 7). The 24-cell grid pattern consists of three north-south columns (A, B and C) and eight east-west rows (1, 2, 3 and 4 for the southern map area of Plate I-A and 5, 6, 7 and 8 for the northern map area of Plate I-B). Rose diagrams for U-2 linears were constructed by tabulation of spatial frequency (number) and azimuth (orientation) using accepted procedures followed in linears-analysis studies. These rose diagrams, and those for SLAR linears, are illustrated together in Figures 8-a and 8-b.

The most obvious limitations to linears recognition in U-2 coverage acquired for this study resulted from vignetting in the prints for the western portion of the area. In many prints the effective stereo resolution was reduced to about 20 percent overlap with darkening and lack of contrast markedly apparent around the margins. This limitation is most obvious in greater openness of the U-2 linear pattern in the southwestern portion of the area (Plate I-A). Vignetting was present on the original film masters

Figure 4.

Photo, mosaic and image coverage

The map depicts the coverage of various remotely sensed data sources used in the Cascade Range linears study. These include:

- High-altitude U-2 infrared photos--shown by stippled area. See Figure 6 for location of individual prints.
- Side-looking airborne radar mosaics--outlined by dotted lines. Southern mosaic is denoted A in this report; it was developed from east-looking radar transmissions. Northern mosaic is denoted B; it was developed from south-looking radar transmissions. Mosaics are on file with the Oregon Department of Geology and Mineral Industries, Portland, Oregon.
- Orbital LANDSAT false color images--outlined by solid lines. Prints are denoted by numbers 1 through 4 in this report.

Characteristics of these data sources are described in Table 1.

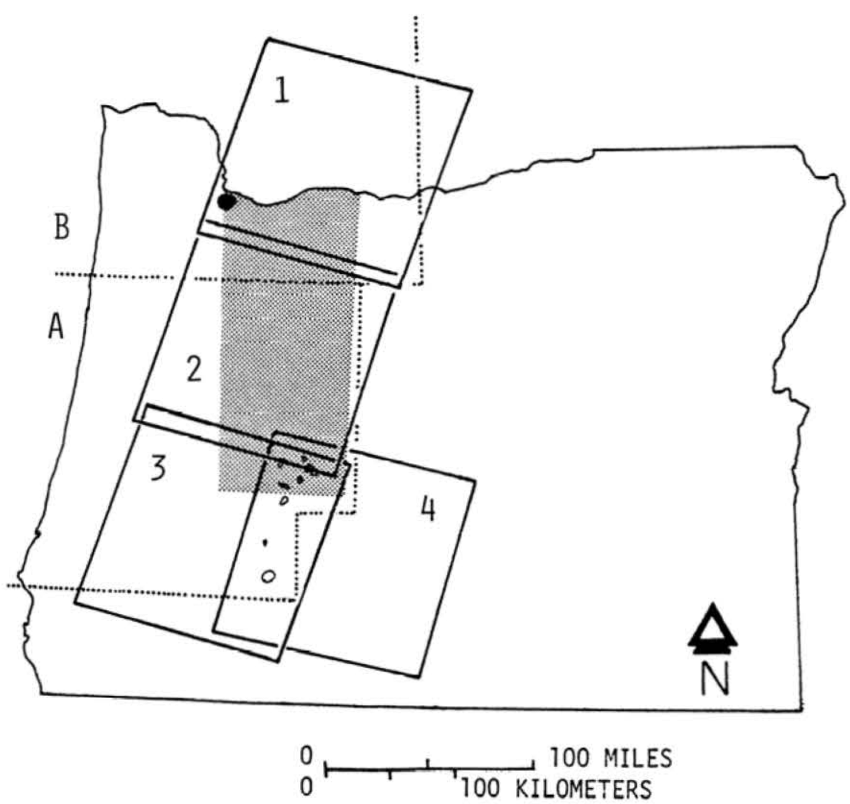


Figure 5.

Image quality

U-2 Frames of U-2 flights (see Figure 6) inside this area have marked image-plane vignetting.

SLAR Dark shaded areas denote mosaic errors which include areas of:

- Omission and duplication.
- Displacement and offset.
- Tonal change across radar-strip overlap.
- Intensive speckling.
- Processing marks and induced features.

LANDSAT Light shaded area denotes area of optimum sun angle (33°) elevation on image (No. 4; Table 1). The remaining images (Nos. 1-3) have relatively high sun angle which appreciably reduces linear enhancement due to topographic shadow accentuation.

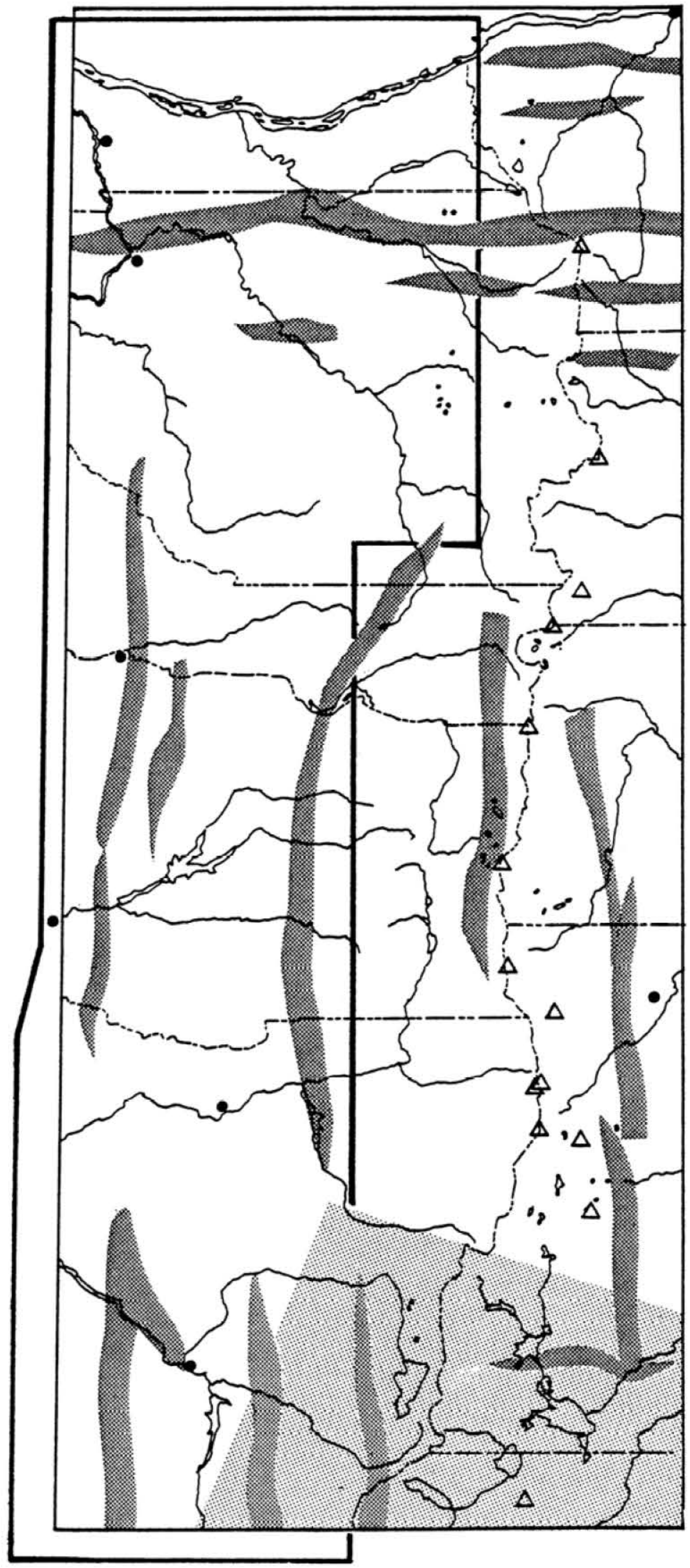
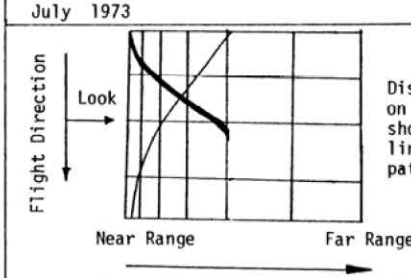


Table 1. Characteristics of remote sensing imagery

Type of Imagery or Photography	1:1,000,000*	1:130,000*	1:250,000*
	LANDSAT MSS Satellite	NASA U-2 Research Aircraft	Westinghouse SLAR Semi-Controlled Mosaic
Type of Data Source	EDIES Enhanced Film Positive	Conventional, High-Altitude Film Positive	Matte-Finish, Paper-Base, Positive Print
	False Color Composite	Color Infrared	Black and White
Acquisition Data:	(4 Images Used)		
Date	1) Aug. 16, 1977 2) Aug. 16, 1977 3) Jun. 23, 1977 4) Oct. 13, 1977	Several dates used; see Figure 6 for details	July 1973
Sun Azimuth & Sun Elevation	1) 126° ; 46° 2) 124° ; 46° 3) 113° ; 55° 4) 146° ; 33°	Sun elevation and azimuth can be obtained from Solar Nomograms	 Distortion effect on linear features shown by curved lines in grid pattern. Increasing loss of detail due to shadowing
Scene Identification	1) E-2 937-17511 2) E-2 937-17514 3) E-2 883-17545 4) E-2 630-18002		
Ground Distance Along One Side of Image or Photograph	N-S 112 mi (180.3 km) E-W 115 mi (185.4 km)	18.4 mi (29.7 km)	Geometry of a typical grid system, distorted due to severe foreshortening at the near-range of one strip of a radar image. Maximum differences in scale due to foreshortening and mosaic matching errors is of the order of 3-6 miles (5-10 km).
Ground Distance Covered by 1" on Photo/Image	15.75 mi (25.4 km)	2.05 mi (3.3 km)	
Resolution Limit**	100'-300' (30-90 m) Average 250' (80 m)	9'-16' (3-5 m)	Highly variable resolution; generally better on the northern sheet. Resolution limit falls off over urban and other developed areas.
Ground Area Covered by One Image or Photograph	12,900 sq mi (33,427 sq km)	340 sq mi (882 sq km)	Each mosaic covers an area about the size of the study area.

*Scale shown (representative ratio) is approximate and is a function of acquisition, processing, terrain and type of imagery.

**Resolution Limit is the smallest possible normal contrast object which can be recognized. It varies with contrast-of-object "signature" in relation to its surroundings and the position of the object within the image or photograph. The resolution range given is the range from a typical low-contrast to high-contrast scene.

Figure 6.

U-2 flight lines

EXPLANATION

Frame	Flight Identification
●—●	75-127 Aug. 4, 1975
○—○	78-107B Aug. 2, 1978
□—□	74-115 Jul. 3, 1974
▷—▷	73-110 Jul. 3, 1973*
▲—▲	74-165 Sep. 24, 1974

◉ Open circle around frame signifies greater than 10 per cent cloud cover in frame.

* This flight line suffers from extreme vignetting.

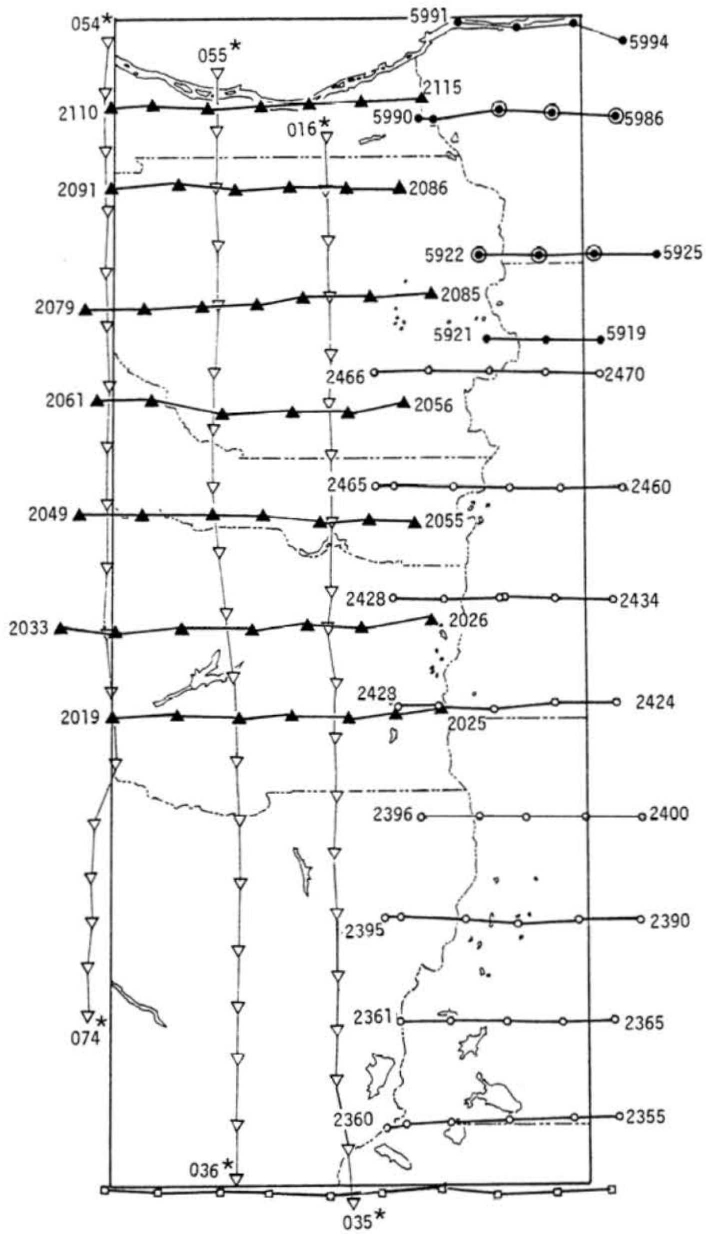


Figure 7.

Land grid

The columns (A, B and C) and rows (1 through 8) depicted here are used for location purposes and for rose diagram preparation in this report. Locations and areas are referred to by column-row designation. Portland, for example, is at A,8.

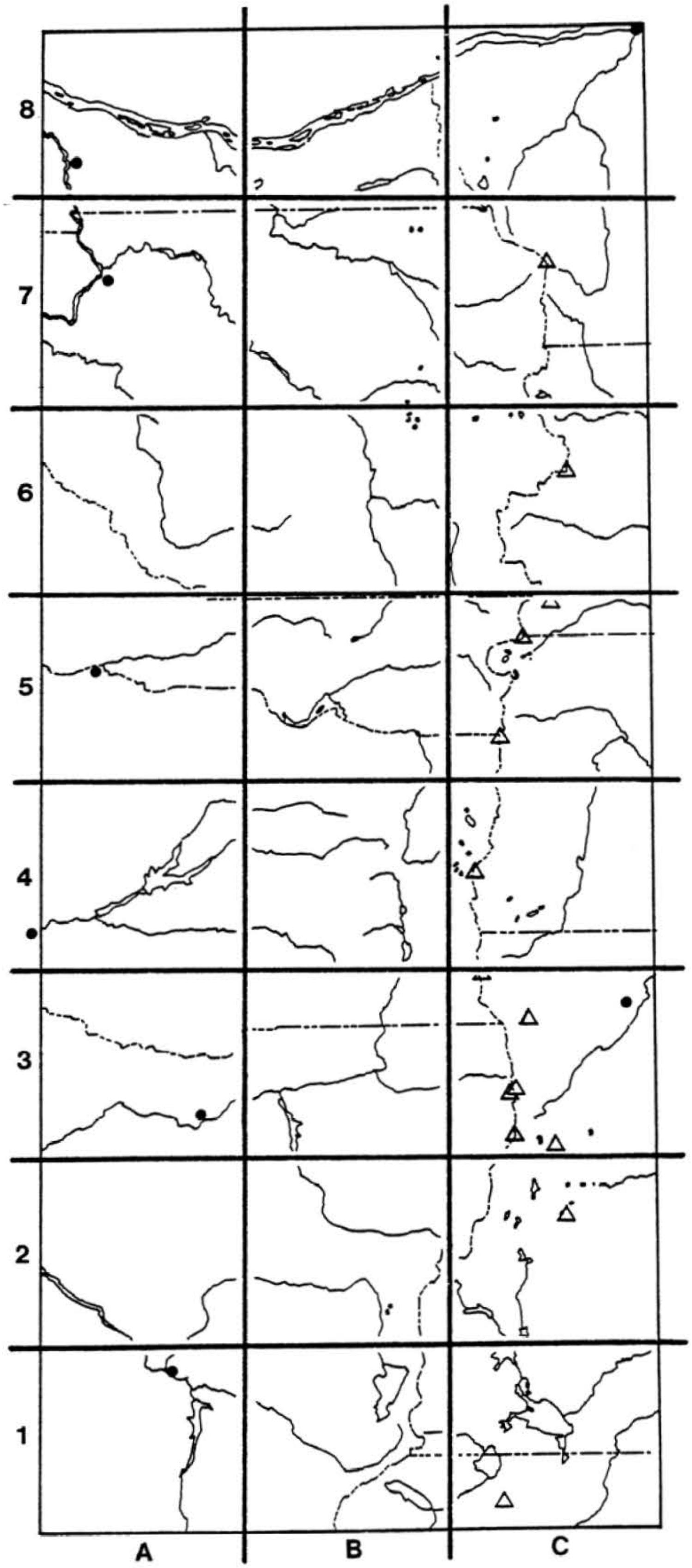


Figure 8-a

Rose diagrams--southern area

Rose diagrams show the frequency of linears in 10° azimuthal categories. U-2 frequency is denoted by open radials; SLAR radials are darkened and overprint U-2 radials. See Figure 7 for geographic location of grid.

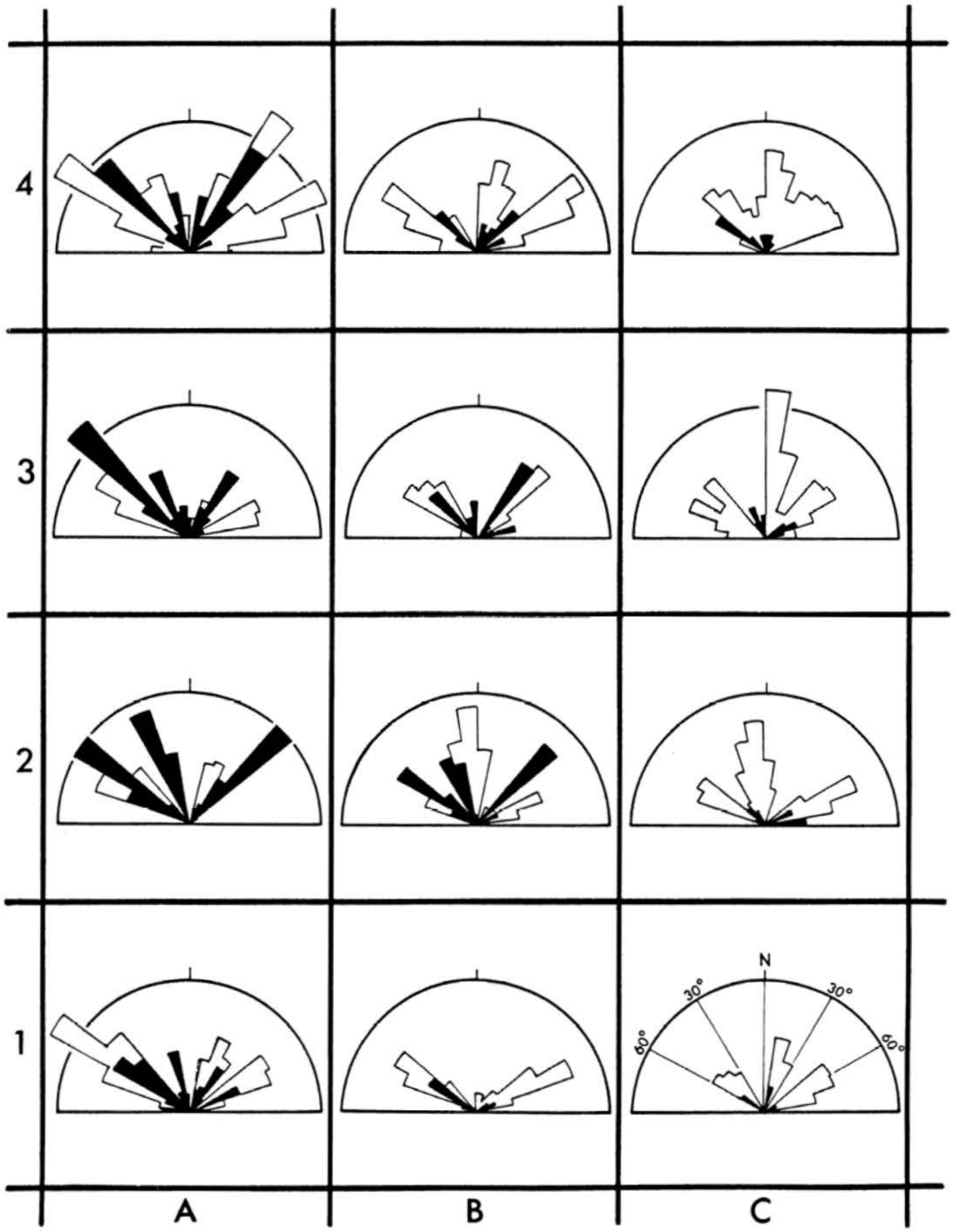
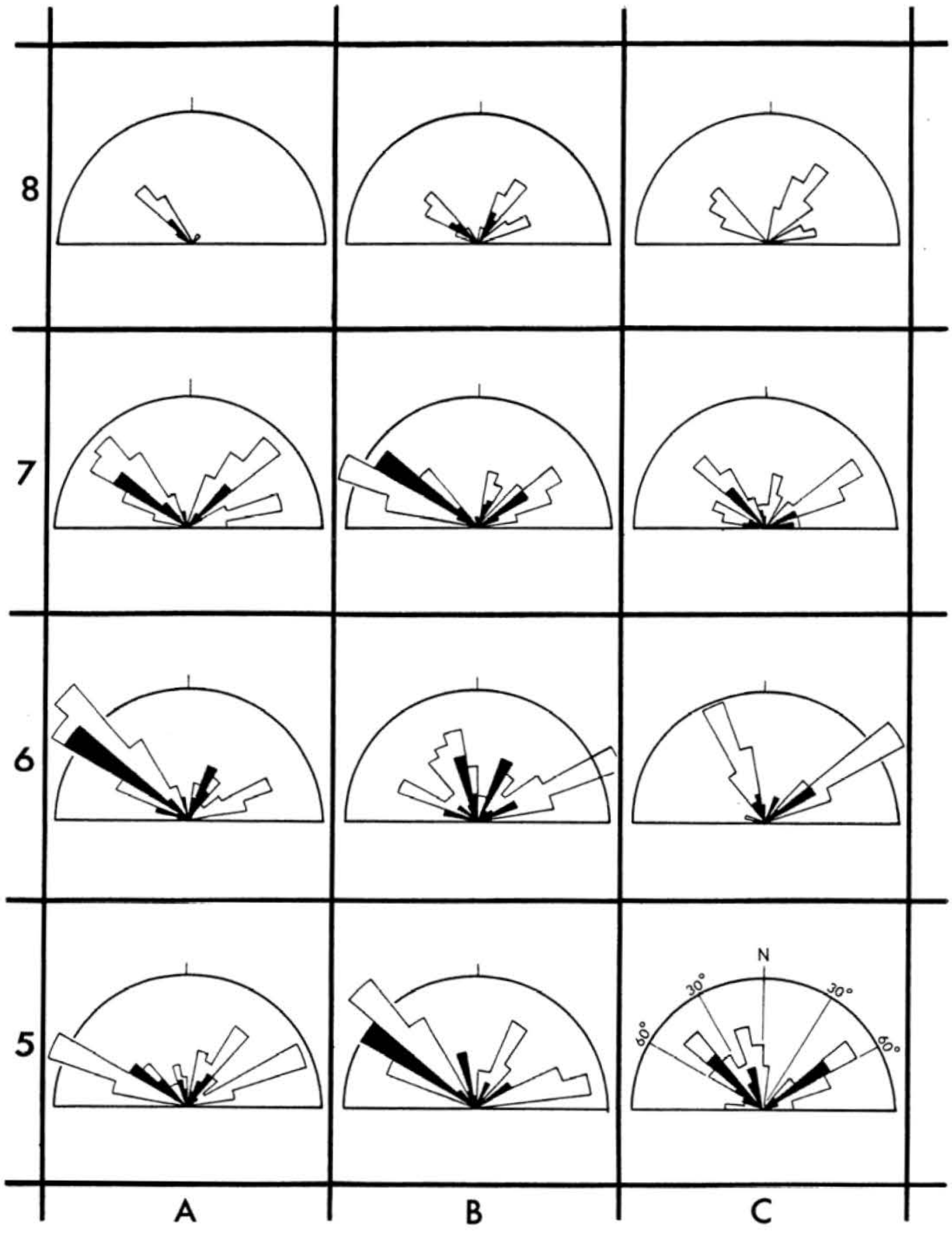


Figure 8-b

Rose diagrams--northern area

Rose diagrams show the frequency of linears in 10° azimuthal categories. U-2 frequency is denoted by open radials; SLAR radials are darkened and overprint U-2 radials. See Figure 7 for geographic location of grid.



provided to the EROS Data Center, Sioux Falls, South Dakota, the principal supplier of prints for this study. Partial compensation was made for vignetting by study of available film from alternate flights covering the same general area which are on file at Battelle Pacific Northwest Laboratories, Richland, Washington.

SLAR mapping

Two SLAR mosaics at approximately 1:250,000 scale were provided to Geoscience Research Consultants by the Oregon Department of Geology and Mineral Industries for the Cascade Range study (Figure 4). The mosaic covering the southern portion of the Cascade Range was synthesized from east-looking radar transmissions. As such it contains a number of north-south shadow zones (Figure 5). The northern mosaic was from south-looking radar imaging and contains some east-west shadowing.

Linears mapping from SLAR mosaics was by direct annotation of features on registered mylar overlays. To correct for distortion, duplication, truncation, tonal change and similar visual characteristics inherent in mosaic preparation and far-look scale change, major topographic features, particularly stream drainages and water bodies, also were annotated on the overlays.

Upon completion of annotation, linears data were transferred to a 1:250,000 scale base map by using a tilt and swing correction mounted zoom transfer scope in order to correct for distortion in the mosaics. Before corrections were applied by using topographic matches, azimuth variations were found to be as much as 30° in proximity to mosaic joins. Duplication, truncation and offset of topographic features on SLAR mosaics which appear as linears at first synoptic inspection proved to be easily eliminated when the annotated features were corrected spatially to base map topography during final transfer. Final compilation is depicted on Plates II-A and II-B. Rose diagrams were constructed for the area from the compilations (Figures 8-a and 8-b).

Two obvious technical limitations to linears determinations using SLAR imagery are present. These are 1) intensive shadowing due to the far-look, low-angle effect of the radar technique combined with the high relief of the Cascade volcanic peaks, and 2) the decreased detectability of features aligned at low angles to look direction (Table 1 and Figure 9).

LANDSAT mapping

Four fully rectified and enhanced multispectral scanner (MSS) false color LANDSAT film positive images at 1:1,000,000 scale were studied for linears (Figure 4). The ground area covered by these four images extends beyond the boundary of the Cascade Range study area. The entire area in Oregon covered on each print was annotated for geologic linears to evaluate the continuation of linear features beyond the study area and to make comparisons with regional geologic maps and lineaments.

The linears mapping technique used with LANDSAT images was similar to that used for U-2 photos and SLAR mosaics. Annotations were made directly on mylar overlays registered to back-lighted images. In the case of LANDSAT, images were annotated twice on separate overlays with a time break between the two inspections. The images also were mapped from different view directions for the replicate studies. Reliability and consistency in linears recognition are considered good based on comparison of results of the two separate annotation steps. Adjustments were made where discrepancies appeared in order to correct for artifacts or cultural features.

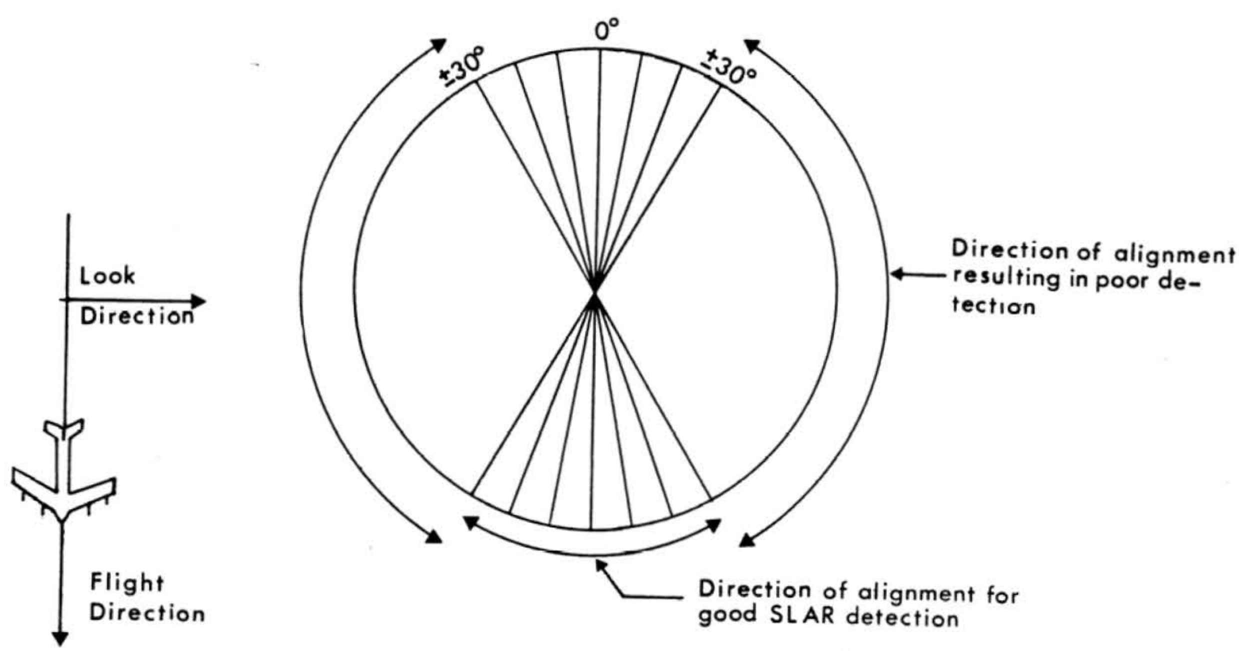
Upon completion of annotation, linears were compiled on one 1:1,000,000 scale base map (Plate III). It was concluded that enlarging annotated LANDSAT linears to 1:250,000 scale would add little to the interpretation and would eliminate the feasibility of retaining a large-area map in one piece for viewing regional patterns. No rose diagrams

Figure 9.

Effect of SLAR look direction

Radar imaging is conducted by "bouncing" electronic impulses off of topographic features. A general rule is--the more solid the feature and the more it is aligned perpendicularly to the impulse, the better will be the reflection of signals from it. Flight direction relative to the orientation of topographic features, including expressions of linears, can markedly affect radar image reception. The diagram indicates the preferred orientation of aligned features to be received the strongest by SLAR imaging. Generally, flight lines which parallel the long direction of aligned features will be most effective in mapping them. However, a greater shadow area will be cast behind ridges by this flight direction.

Table 1 depicts the distortion which also is present from side-looking image techniques.



were constructed for LANDSAT linears; the density of linears identified from this data source was too low to have significance in the land grid that was used for U-2 and SLAR tabulations.

As in most studies using orbital imagery, the major limitation found in its application during this study is lack of detail. However, virtually all major linear trends recognized in the area on lower altitude prints were recognized on LANDSAT. In addition, lineaments, as the Eugene-Denio zone, were recognized. It was encouraging to note that lineations due to east-west scan-line direction for LANDSAT imaging had been removed effectively during computer processing, rectification and enhancement of the remotely sensed data; no such lineal features were recognized during annotation.

Comparison of U-2, SLAR and LANDSAT Linears Mapping

A qualitative assessment of the three image sources used for this study reveals several marked differences among them for linears mapping and also qualifies the relative merits and limitations of each for this type of linears work. In this discussion, locations are referred to by the same grid pattern as that which was used for rose diagram preparations (Figure 7). As noted at the beginning of the chapter, specific photo and imagery parameters affected by scales of U-2, SLAR and LANDSAT renditions are summarized in Table 1.

Overall, U-2 photos, particularly infrared film positive prints, are judged to be substantially better for geologic linears mapping than the other sources utilized. The linears mapped from photos obtained from this high-altitude platform, however, are much shorter in length than those from SLAR and LANDSAT. This can be attributed to breaks in visual continuity along individual linear features which can be recognized in U-2 products but which are not present in renditions of smaller scale SLAR and LANDSAT. In other words, the latter two gloss over much of the detail and merge or connect together linear segments which a photointerpreter can resolve on larger scale U-2 prints.

U-2 imagery generally yields a greater number of linears, by 4 to 5 times, per unit area than does SLAR, which in turn yields more than LANDSAT imagery. However, the fact that U-2 photos cover smaller areas on the ground in each print relative to the other forms generally does not permit the detection of large regional structures and patterns. The principal advantages of the U-2 prints, then, are substantially greater ground resolution and overall precision for ground-truth verification.

All three data sources clearly picked out longer segments of such linear trends as N50°-70°W and N40°-60°E throughout the Cascade Range study area. A visual appraisal of rose diagrams (Figure 8-a and 8-b) immediately brings out differences in U-2 and SLAR linears recognition. In column C, row 1 (C,1), for example, the spatial density of linears is vastly different. As previously indicated, low linears detection in SLAR mosaics can result from intensive shadowing due to far-range look and to high relief of the Cascade volcanic peaks. An increase in east-to-west SLAR linears density relative to those of U-2 appears to be directly related to relative decrease in topographic relief in that direction.

Of particular significance also is the observation that north-south linears found by U-2 inspection to be common in the High Cascades are not consistently detected on SLAR (C,1 through C,4). This is despite the optimum orientation of radar transmissions for picking up north-south aligned features in the southern portion of the study area. In contrast, in the lower relief of the Western Cascades, long north-northwesterly trending linears annotated on SLAR mosaics appear to be enhanced by their optimum orientation to radar detection; these are much less obvious on U-2 prints.

Azimuthal detection limitations of the SLAR method relative to lineal features aligned at angles close to look direction also appear to be recognizable for some linear trends. In the southern area (A,4; A,5; B,1; B,4 and possibly C,1; C,2 and C,3) the persistent N50°-70°W linear set, as noted on rose diagram peaks for U-2 tabulations, has not been picked up as strongly from linears mapping on the southern SLAR mosaic. This linears trend is at low angle to the radar transmission direction and outside the optimum detection angle for aligned features (Figure 9).

One additional comparative factor should be noted for the apparent imbalance between U-2 and SLAR linears tabulations on rose diagrams. The greater number of linears obtained from U-2 inspection is to a minor degree an artifact of greater resolution along individual linears on U-2 photos; this leads to breaks or offsets in visual continuity of linears on and between adjacent stereo images. A greater number of individual linears of a set will be counted in U-2 annotation as a result. Statistical analysis currently is being conducted as an independent study to test the significance of this bias factor and also to evaluate the significance of the smaller, but persistent peaks obtained from SLAR mosaic annotations which are slightly offset in azimuth relative to U-2 linears annotations (A,2; B,3 or B,5 for example).

Discussion of Linears

The distribution, persistence and orientation of geologic linears in the Cascade Range study area (Plates I, II and III; Figure 8) can be characterized as follows:

- Mapped linears are predominantly rectilinears.

- Rectilinears occur in sets of varying close and wide spacing; these systematic sets are separated from one another by angles of 30° or more in azimuth.

- All subjective levels of mapping--from strong linear expression through subtle linear expression--give linears with consistent spatial and azimuthal characteristics so that all levels of linears make up parts of linear sets.

- Sets of systematic rectilinears intersect one another to give persistent linear patterns which extend over hundreds of square miles.

- All major rectilinear trends are mappable to varying degrees on all three types of imagery used in the study.

- Dominant sets of rectilinears occur at N50°-70°W and at N40°-60°E; however, these sets rotate as much as 10° either way across the area. Locally a N10°W ± 10° linear set is well expressed.

- Area-wide, the N50°-70°W linear set obtained from U-2 and SLAR sources generally has longer segments than the N40°-60°E set; locally, however, the two intersecting sets may have very similar segment lengths.

- Rectilinear sets do show changes in intensity (mappability) across the area so that different dominant and subordinant sets show levels of expression as noted by peaking on rose diagrams. In particular, a N10°-30°W linear set is expressed on SLAR mosaics which is not revealed on U-2 and LANDSAT images.

- Region-wide, linear patterns do exhibit moderately different orientations and densities, particularly if large-area LANDSAT perspective is applied.

- Curvilinears, where present, generally are small and circular; that is--they close on themselves or would do so if projected along trend.

These general characteristics, when considered in geologic and geographic perspective, appear to be related to the following conditions:

·Rectilinears crosscut areas of high relief with no significant bending or apparent deflection. This indicates that the fractures which they denote are very steeply dipping (greater than 70°) to vertical.

·The relatively systematic orientation of rectilinears and linear sets, as determined from U-2 photos, crosscut virtually all bedrock terrains without marked change in azimuth. This suggests that all volcanic bedrock in the area is responding to common geologic and tectonic conditions and stresses.

·The intersection of rectilinear sets into patterns which do not show consistent offset or displacement within themselves is considered to indicate that the systematic linears are conjugate sets and that the common geologic and tectonic conditions and stresses inferred above are primarily related to a single event, episode or stress field.

·Rectilinears, as annotated from large-area LANDSAT images, do not persist across the volcanic cone backbone of the High Cascades although they are present on both sides. This is interpreted to mean that fractures which gave rise to the rectilinears apparent on U-2 photos have not been as well etched by surficial processes so that they do not show up on the small-scale LANDSAT renditions. The lack of effective etching is most likely due to the relatively young geologic age of the High Cascades.

·Concentrations of strong nearly north-south (N10°W ±10°) linears along the eastern portion of the study area conform to the alignment of High Cascade volcanic peaks and their associated flank vents and plugs; this relation appears to be syngenetic, particularly in the absence of effective fracture-etching noted above.

·Direct correlation between specific linears and mapped fault structures and zones is apparent as in the Metolius Fault Zone on the eastern flank of the High Cascades and along the Willamette River in the Western Cascades.

·Direct correlation between linear sets and the north-northeasterly alignment of broad anticlinal and synclinal axes in the Oligocene-Miocene volcanic units exposed in the Western Cascades is unclear. It may be reflected by a subordinate linear set denoted at N15°-30°E on rose diagrams covering that area.

·The region-wide change of linear patterns recognizable on LANDSAT images, as is apparent southward and eastward in Oregon, is considered to indicate that adjoining areas have undergone different tectonic histories or that the different rock types and basement structures in these areas are responding differently to the same tectonic forces.

·Direct correlation between long linear trends and proposed lineaments, as the Eugene-Denio zone, can be made from LANDSAT annotations.

·Curvilinears match up well with specific bedrock units and are considered to confirm locations of eroded volcanic cones and related features in areas of upper Tertiary and younger eruptions. The general absence of curvilinears on SLAR which is less sensitive to vegetation and tonal breaks strongly supports this setting where no fractures are involved. More precisely speaking, curvilinears in this map area generally do not qualify as geologic linears because fracturing is not being annotated.

Linears Analysis

In this concluding section of the report dominant linears and their intersecting pattern are considered in respect to reported regional tectonic regimes. In overview, the pattern of linears observed in the Cascade Range study area is interpreted to be explained best in terms of a regional tectonic stress field which is reflected by major strike-slip or wrench faulting with a right lateral sense of movement. Details for this preferred wrench-fault tectonism have been obtained from several published reports and papers where general structural patterns discussed are similar to that observed in the Cascade Range study. However, to the authors' understanding, no detailed study of this nature has been undertaken to correlate linear patterns, volcanic alignments and known mapped faults for regional synthesis in the study area. This summary of preliminary findings is included to present added data in hopes of stimulating further discussion. Detailed and statistical evaluation currently is in progress as an independent study by the authors.

Major parameters which have guided this analysis have been outlined previously. To recapitulate very briefly:

- The linear trends are dominantly represented by straight lines; because the topography is not flat, most of the planes of fracture are interperted to be vertical or nearly so.
- The different rock formations present in the study area do not yield notably different linear patterns so it is reasonable to conclude that a relatively uniform regional stress situation is applicable and that linear sets are conjugate sets.
- The bulk of curvilinear features are believed to be expressions of eroded volcanic cones and associated forms and not to denote structural fabric in the area.

The analysis also is based on the hypothesis that observable linear patterns in a given area reflect the state of stress prevalent in that area at the time that fracturing took place. In addition, it is assumed that near-surface crustal material in the Cascade Range study area underwent brittle fracture when strain reached the breaking point. This analysis also has concluded that fracture mechanisms in which Cascade Range rocks act as "cover rocks" over "basement faults" analogous to Riedel experiments (Tchalenko and Ambraseys, 1970) probably do not apply. It is more likely that the volcanic units were involved in or responding to the fracture mechanism. This latter is pertinent to the discussion because the direction and magnitude of regional principal stress will, therefore, also control any purely tectonic faulting that may occur. This is to say that there will be an association between the types of regional faulting and the kind, disposition and temporal association of volcanic activity found in a region.

Mechanics and terminology of strike-slip or wrench faulting under horizontal compression are depicted in Figure 10. These are applied in the linears analysis summary which follows.

Based on the dominant N50°-70°W and N40°-60°E linear sets and the localized N10°W ±10° linear set of the High Cascades, the strain ellipse for the study area when fracturing took place had the following average orientation:

- Maximum stress axis (maximum compression--σ_1) is horizontal in a N10°W ±10° direction.
- Intermediate stress axis (moderate compression--σ_2) is vertical.
- Minimum stress axis (minimum compression to relative tension--σ_3) is horizontal and at right angles to maximum stress axis at about N80°E ±10°.

Figure 10.

Stress failure mechanisms

The angular relationships between principal compressive stress and failure surfaces are depicted diagrammatically; these have been used to resolve the linear pattern in the study area into a proposed stress field and rock response. The stress configuration is shown in strike-slip faulting in the upper diagram. A plan view of the strain ellipse is at the bottom. Componants are:

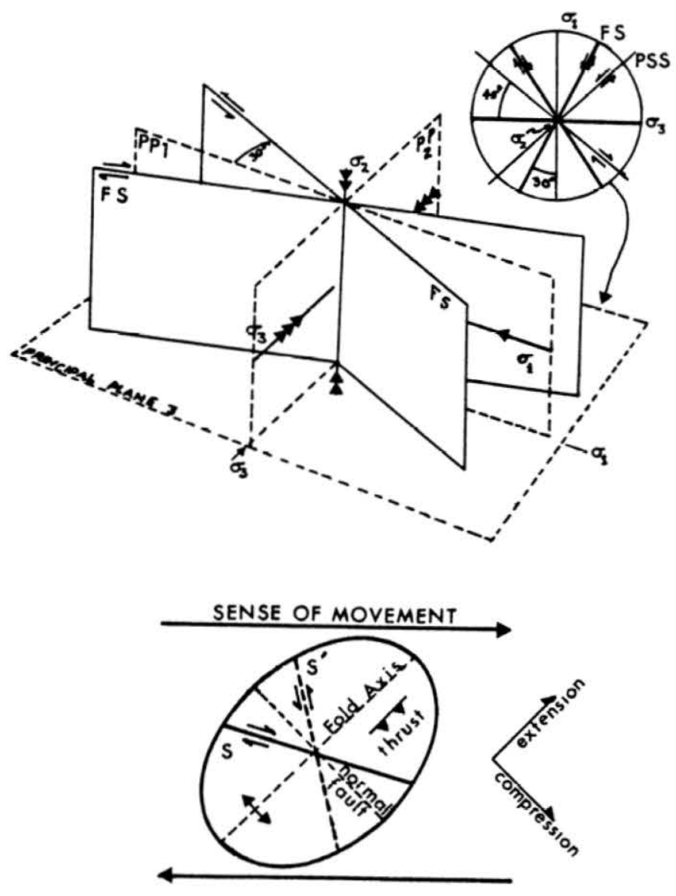
σ_1--maximum compressive stress.

σ_2--intermediate compressive stress.

σ_3--minimum compressive stress.

$PP_{1,2,3}$--principal planes corresponding to the three compressive stresses.

S, S'; FS--conjugate shear planes or failure surfaces representing simple-shear in strike-slip faulting.



This state of stress would lead to strike-slip faulting within the area and result in stress relief in a northeasterly and/or northwesterly direction; that is the N50°-70°W and N40°-60°E linear fracture pattern in the map area. The direction along which relief occurred first, or preferably, would become the most dominant fracture direction in that particular deformation regime. The N50°-70°W linear set is interpreted to be the preferred failure plane direction. A diagrammatic representation of this tectonic stress regime is shown on Figure 11.

The regional segmentation which resulted from such strike-slip relief that is proposed to apply to the tectonic setting of the area is a northward extension of the tectonic setting proposed by Lawrence (1976) for southern Oregon and northern California. Lawrence, however, did not extend the major segmenting strike-slip zones or lineaments west of the High Cascades in Oregon except for the Eugene-Denio and McLoughlin zones south of the study area. The more northerly location and areal distribution of the proposed northwest-trending lateral shear zones of this interpretation are based on the consistent linear trends of the many northwesterly flowing tributaries of the Willamette River. These lineal features are interpreted to reflect subtle expression of extensions of such features as the Brothers zone terminated by Lawrence at the Three Sisters. These trends appear to be traceable in remotely sensed data into the Willamette Basin and farther westward into coastal ranges. The somewhat subdued nature of the surface traces within the Cascade Range, as linearity of stream segments, together with the en-echelon arrays of normal faults above the postulated shears east of the Cascade Range, suggests that the shear zones are deep seated.

Nakamura and others (1977) proposed a method of using volcanoes as indicators of tectonic stress which they systematically applied to Alaskan and Aleutian volcanoes. Regional uniformity in orientation of flank volcanoes along linear and parallel flank zones are considered indicators of tension (σ_3) at right angles to compression (σ_1). Such a tensional setting provides avenues for magma passage and lineal flank eruptions. When this analogy is carried to the volcanic cones and lineal flank eruptions of the High Cascades of Oregon, it appears reasonable to conclude that the same stress association applies, especially when one considers volcanism to be concurrent with tectonism and that a tectonic setting similar to that of Lawrence discussed above would match the stress orientations for such lineal flank eruptions.

One additional factor which can be noted in this brief linears discussion on resolution of stress analysis is the basalt-andesite association of Christiansen and Lipman (1972). They have shown "fundamentally basaltic" and "fundamentally andesitic" volcanism in the western United States to be related both in time and space with extensional and contractional tectonic styles. Older Columbia River Basalt Group eruptive fissures are considered extensional and younger Cascade andesite eruptive features are principally contractional. At the present stage of the Cascade Range study this relationship also appears to have been met by the proposed setting.

Figure 11.

Generalized structural interpretation

A proposed tectonic setting is depicted based on linears analysis of the Cascade Range data. Most representations are diagrammatic and do not represent specific linears Identified components are:

1 Clackamas River trend

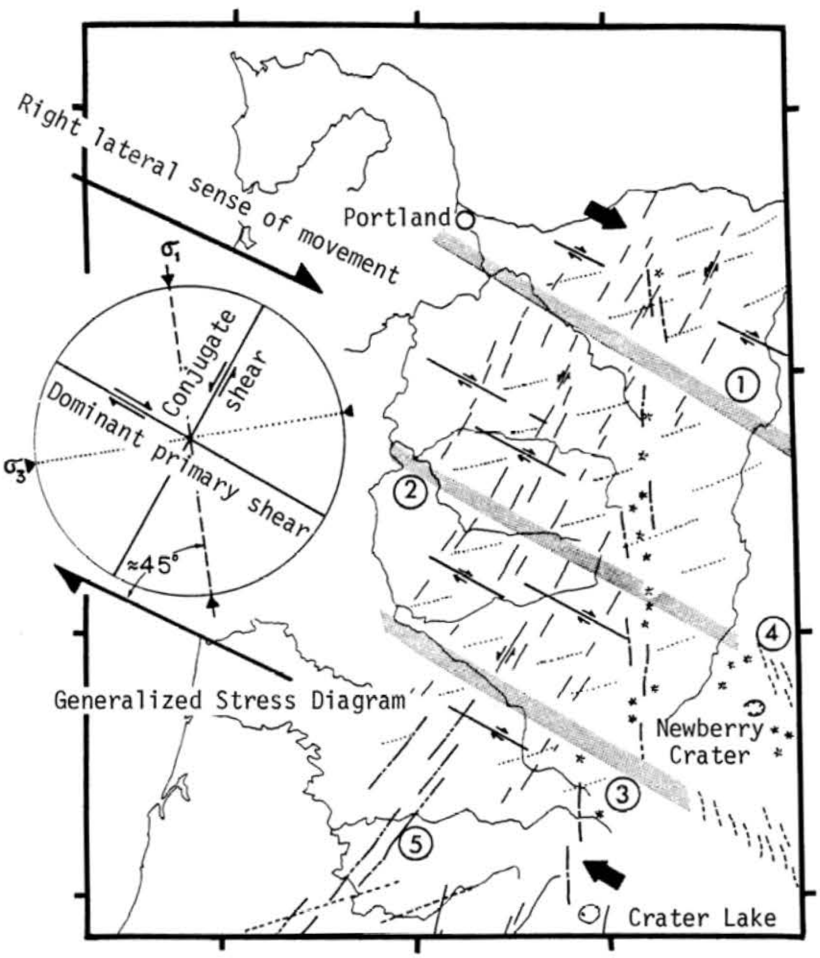
2 Brothers zone extension into the Cascades

3 Eugene-Denio zone

4 Brothers zone expression east of the Cascade Range

5 Klamath Mountain trend

◀ Major sense of movement within the Cascade Range



REFERENCES CITED

Carey, S. W., 1958, Continental drift: A symposium, University of Tasmania, Geology Department, pp. 177-355.

Christiansen, R. L., and Lipman, P. W., 1972, Cenozoic volcanism and plate-tectonic evolution of the western United States, II Late Cenozoic: Philos. Trans. Royal Soc. Lond., Sec. A., pp. 217-248.

Gay, S. P., Jr., 1972, Fundamental characteristics of aeromagnetic lineaments: Salt Lake City, Utah, Am. Stereo Map Co., 94 pp.

Hobbs, W. H., 1912, Earth features and their meaning: New York, New York, MacMillian Co., 506 pp.

Hodgson, R. A., 1974, Editor: Proceedings of the First International Conference on the "New Basement Tectonics": Utah Geological Association, Publication 5, 636 pp.

Lapworth, C., 1892, The heights and hollows of the earth's surface: Proc. Royal Geogr. Soc., Vol. 14., p. 688-697.

Lawrence, R. D., 1976, Strike-slip faulting terminates the Basin and Range Province in Oregon: Geol. Soc. Am. Bull. 87, pp. 846-850.

Maxwell, J. C., and Wise, D. V., 1958, Wrench-fault tectonics: A discussion, Geol. Soc. Am. Bull. 69, pp. 927-928.

McBirney, A. R., 1978, Volcanic evolution of the Cascade Range: Ann. Rev. Earth Planet. Sci. 6, pp. 437-456.

Moody, J. D., 1974, Petroleum exploration aspects of wrench-fault tectonics: Am. Assoc. Petrol. Geol. Bull. 57, pp. 449-476.

Moody, J. D., and Hill, M. J., 1956, Wrench-fault tectonics: Geol. Soc. Am. Bull. 67, pp. 1207-1246.

Nakamura, K., Jacob, K. H., and Davies, J. N., 1977, Volcanoes as possible indicators of tectonic stress orientation--Aleutians and Alaska: Pageoph., Vol. 115, Birkhäuser Verlag, Basel, pp. 87-112.

O'Leary, D. W., Friedman, J. D., and Pohn, H. A., 1976, Lineament, linear and lineation: Some proposed new standards for old terms: Geol. Soc. Am. Bull. 87, pp. 1463-1469.

Peck, D. L. 1961, Geologic map of Oregon west of the 121st meridian: U. S. Geol. Surv. Map I-325.

Raisz, E. J., 1945, The Olympic-Wallowa lineament: Am. Jour. Sci. 243A (Daly Volume), pp. 479-485.

Rance, H., 1967, Major lineaments and torsional deformation of the earth: Jour. Geophys. Res. 72, pp. 2213-2217.

Shul'ts, S. S., 1971, Planetary fractures and tectonic deformation: Geotectonics No. 4, pp. 203-207.

Tchalenko, J.S., and Ambraseys, N.N., 1970, Structural analysis of the Dasht-e Bāyaz (Iran) earthquake: Geol. Soc. Am. Bull. 81, pp. 41-59.

Venkatakrishnan, R., Hall, W. B., and Reid, R. R., 1980, Fracture analysis of Coeur d'Alene area, phase I, linear analysis: Open-file report, Idaho Mining and Mineral Resources Research Institute, 64 pp.

Wilcox, R. E., Harding, T. P., and Seely, D. R., 1973, Basic wrench tectonics: Amer. Assoc. Petrol. Geol. Bull. 57, pp. 74-96.

STATE OF OREGON
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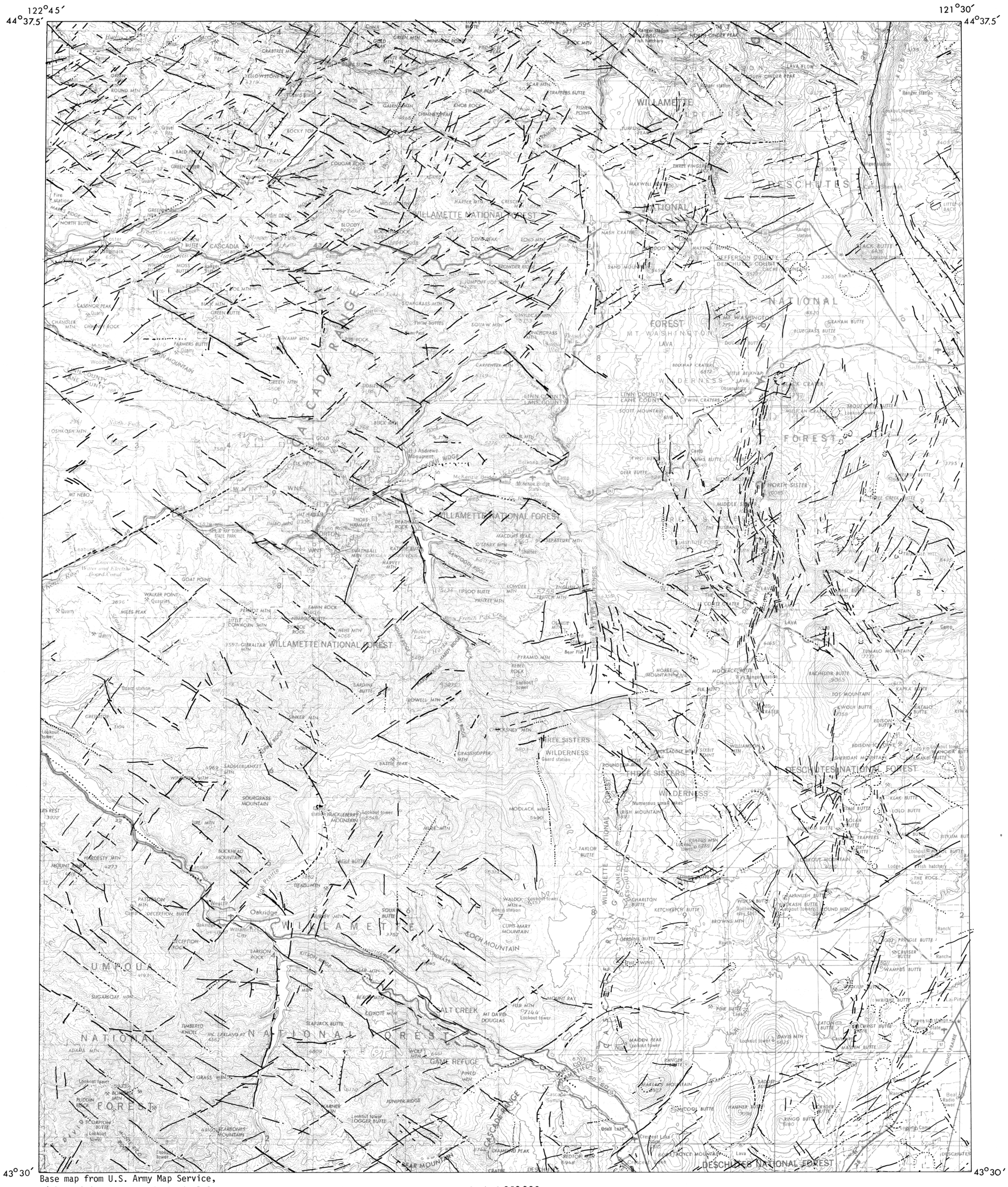
PLATE I-A

(SOUTHERN PORTION)

GEOLOGICAL LINEARS OF THE NORTHERN PART OF THE CASCADE RANGE, OREGON

(LINEARS DERIVED FROM HIGH-ALTITUDE COLOR INFRARED AERIAL PHOTOGRAPHS)



Base map from U.S. Army Map Service, with revisions by U.S. Geological Survey

Scale 1:250,000

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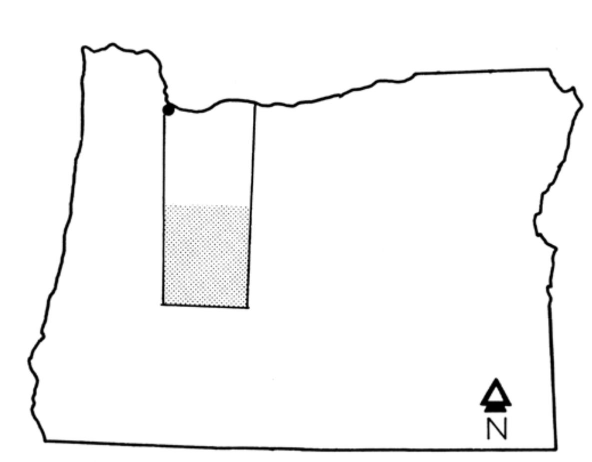
5 0 5 10 15 20 25 30 Kilometers



MAP SYMBOLS

Strong linear expression--generally a geomorphic anomaly expressed in the form of a long, pronounced straight valley, stream segment, ridge crest or tonal change. Bars on linears express probable downthrown displacement.

En-echelon linear expression--numerous small lineal segments arranged sequentially, possibly forming a longer linear. Many of these appear to be tonal or vegetative expressions of bedrock structures

Subtle linear expression--generally consists of short straight topographic features. Segments of this linear symbol placed between or at the end of the classes above signify extrapolation or inference of linears.

The above linear classes express the image interpreters' confidence in linears recognition; order of decreasing confidence is top to bottom.

Circular linear expression--possibly remnants of eroded volcanic cones or vents.

Area obscured by cloud cover

Prepared in conformance with ORS 516.030
Funded in part under U.S. Department of Energy Contract DE-FC07-79ID12044

INTERPRETATION BY
RAMESH VENKATAKRISHNAN
JOHN G. BOND
JOHN D. KAUFFMAN
1980

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
DONALD A. HULL, STATE GEOLOGIST

SPECIAL PAPER 12

PLATE I-B

(NORTHERN PORTION)

GEOLOGICAL LINEARS OF THE NORTHERN PART OF THE CASCADE RANGE, OREGON

(LINEARS DERIVED FROM HIGH-ALTITUDE COLOR INFRARED AERIAL PHOTOGRAPHS)

122°45′ 45°45′

121°30′ 45°45′

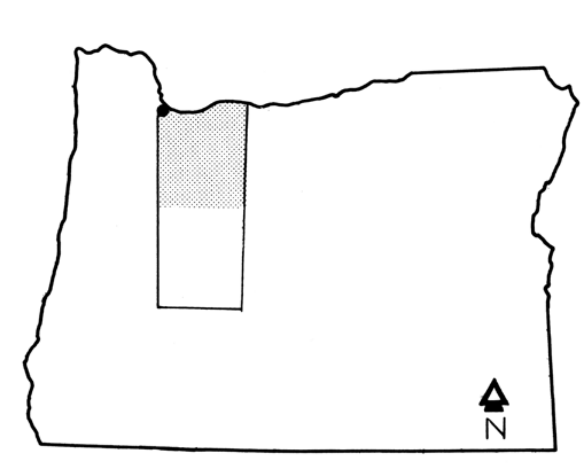
44°37.5′ 44°37.5′

Base map from U.S. Army Map Service, with revisions by U.S. Geological Survey

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers



MAP SYMBOLS

Strong linear expression--generally a geomorphic anomaly expressed in the form of a long, pronounced straight valley, stream segment, ridge crest or tonal change. Bars on linears express probable downthrown displacement.

En-echelon linear expression--numerous small lineal segments arranged sequentially, possibly forming a longer linear. Many of these appear to be tonal or vegetative expressions of bedrock structures

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Circular linear expression--possibly remnants of eroded volcanic cones or vents.

Area obscured by cloud cover.

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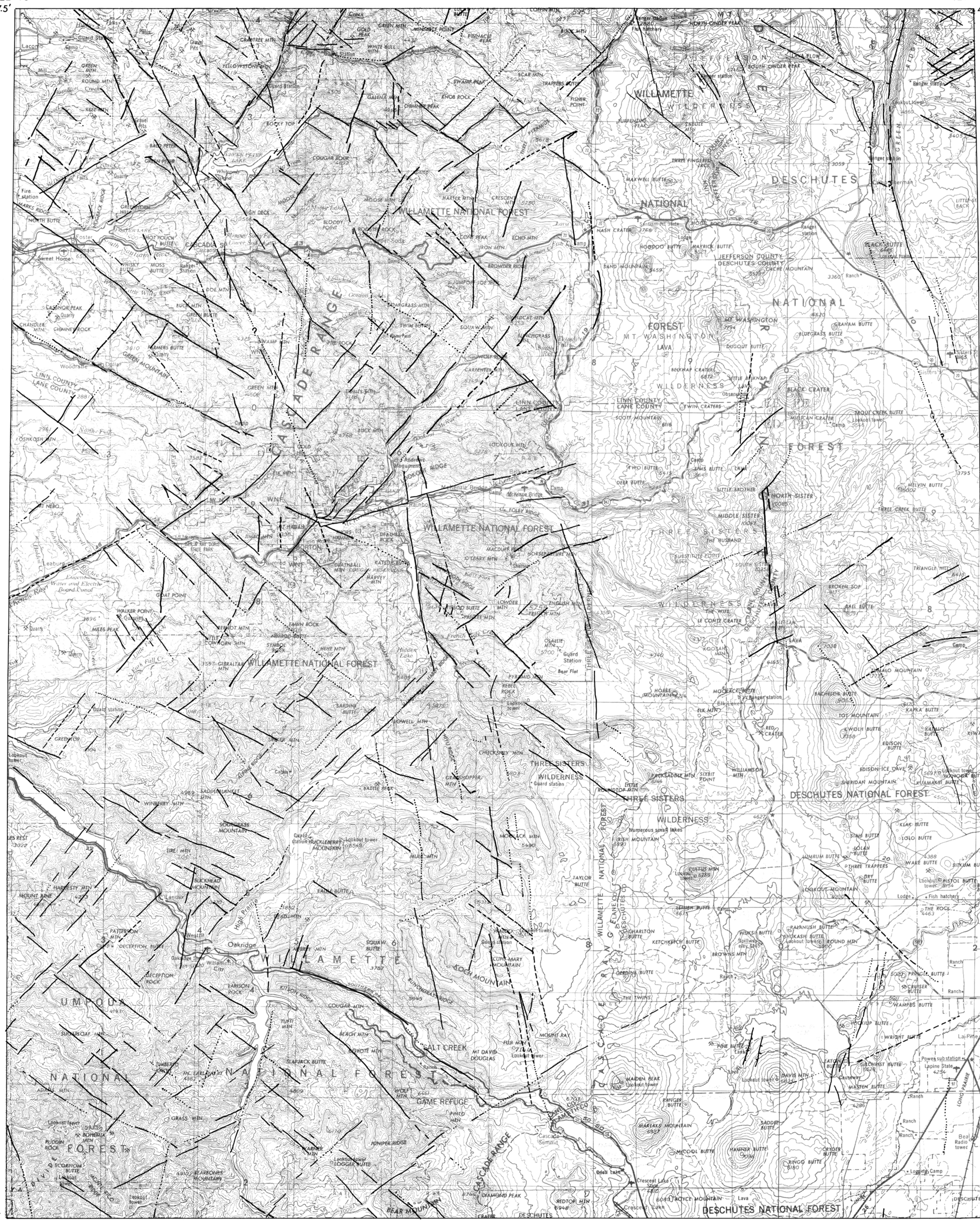
PLATE II-A

(SOUTHERN PORTION)

GEOLOGICAL LINEARS OF THE NORTHERN PART OF THE CASCADE RANGE, OREGON

(LINEARS DERIVED FROM SIDE-LOOKING AIRBORNE RADAR (SLAR) MOSAIC)

122°45′ 44°37.5′ — 121°30′ 44°37.5′



43°30′ — 43°30′

Base map from U.S. Army Map Service, with revisions by U.S. Geological Survey

Scale 1:250,000

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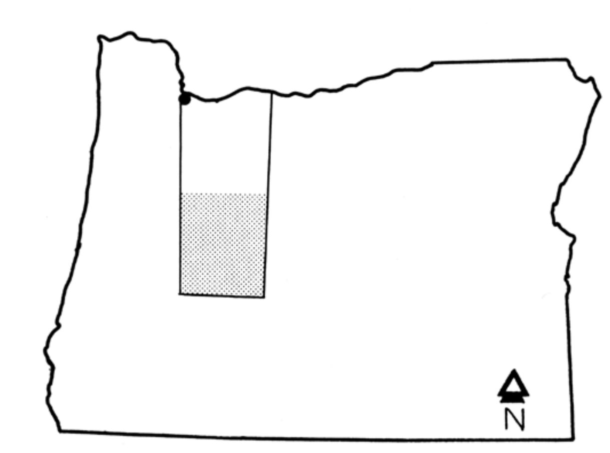
5 0 5 10 15 20 25 30 Kilometers



MAP SYMBOL

Strong linear expression--generally a geomorphic anomaly expressed in the form of a long, pronounced straight valley, stream segment, ridge crest or tonal change. Bars on linears express probable downthrown displacement.

En-echelon linear expression--numerous small lineal segments arranged sequentially, possibly forming a longer linear. Many of these appear to be tonal expression of bedrock structures.

Subtle linear expression--generally consists of short straight topographic features. Segments of this linear symbol placed between or at the end of the classes above signify extrapolation or inference of linears.

The above linear classes express the image interpreters' confidence in linears recognition; order of decreasing confidence is top to bottom.

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DONALD A. HULL, STATE GEOLOGIST

SPECIAL PAPER 12

GEOLOGICAL LINEARS OF THE NORTHERN PART OF THE CASCADE RANGE, OREGON

(LINEARS DERIVED FROM SIDE-LOOKING AIRBORNE RADAR (SLAR) MOSAIC)

122°45′ 45°45′ — 121°30′ 45°45′

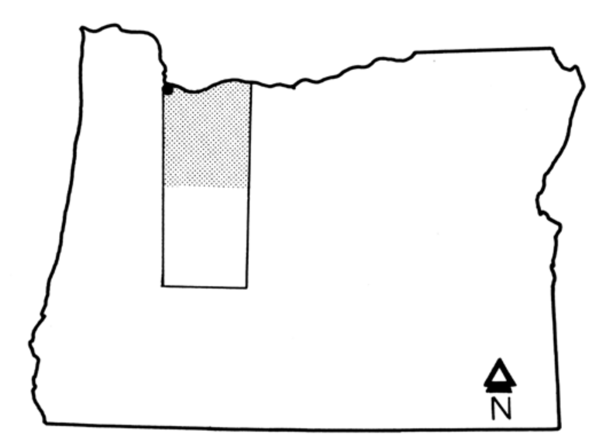
44°37.5′ — 44°37.5′

Base map from U.S. Army Map Service,
with revisions by U.S. Geological Survey

Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers



MAP SYMBOLS

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En-echelon linear expression--numerous small lineal segments arranged sequentially, possibly forming a longer linear. Many of these appear to be tonal expression of bedrock structures.

Subtle linear expression--generally consists of short straight topographic features. Segments of this linear symbol placed between or at the end of the classes above signify extrapolation or inference of linears.

The above linear classes express the image interperters' confidence in linears recognition; order of decreasing confidence is top to bottom.

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1980

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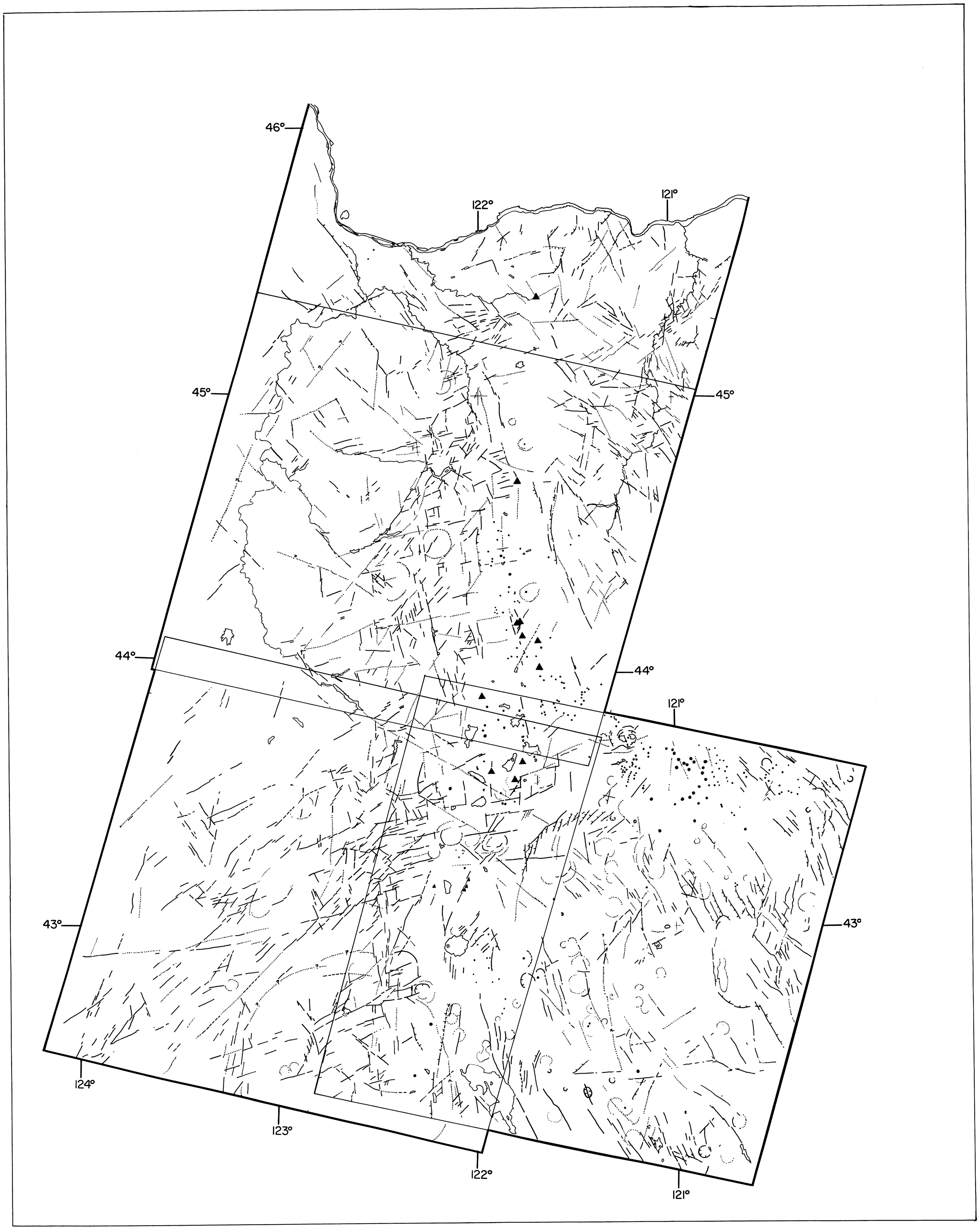
PLATE III

GEOLOGICAL LINEARS OF THE NORTHERN PART OF THE CASCADE RANGE, OREGON

(LINEARS DERIVED FROM LANDSAT MSS IMAGES)



Scale 1:1,000,000

20 0 20 40 60 80 Statute Miles

20 0 20 40 60 80 100 120 Kilometers

MAP SYMBOLS

Strong linear expression--generally a geomorphic anomaly expressed in the form of a long, pronounced straight valley, stream segment, ridge crest or tonal change. Bars on linears express probable downthrown displacement.

En-echelon linear expression--numerous small lineal segments arranged sequentially, possibly forming a longer linear. Many of these appear to be tonal or vegetative expressions of bedrock structures

Subtle linear expression--generally consists of short straight topographic features. Segments of this linear symbol placed between or at the end of the classes above signify extrapolation or inference of linears.

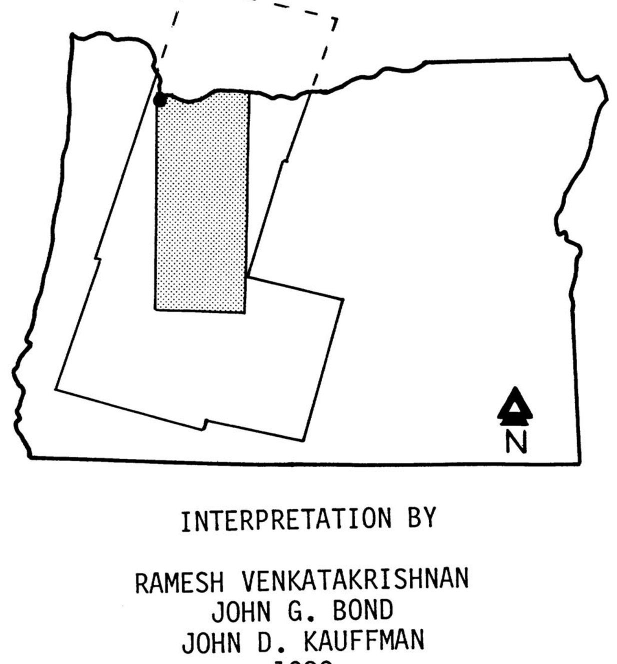
The above linear classes express the image interpreters' confidence in linears recognition; order of decreasing confidence is top to bottom.

Circular linear expression--possibly remnants of eroded volcanic cones or vents.

Area obscured by cloud cover.

Major andesite cone.

Minor andesite or basalt cone; many are flank eruptions.



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