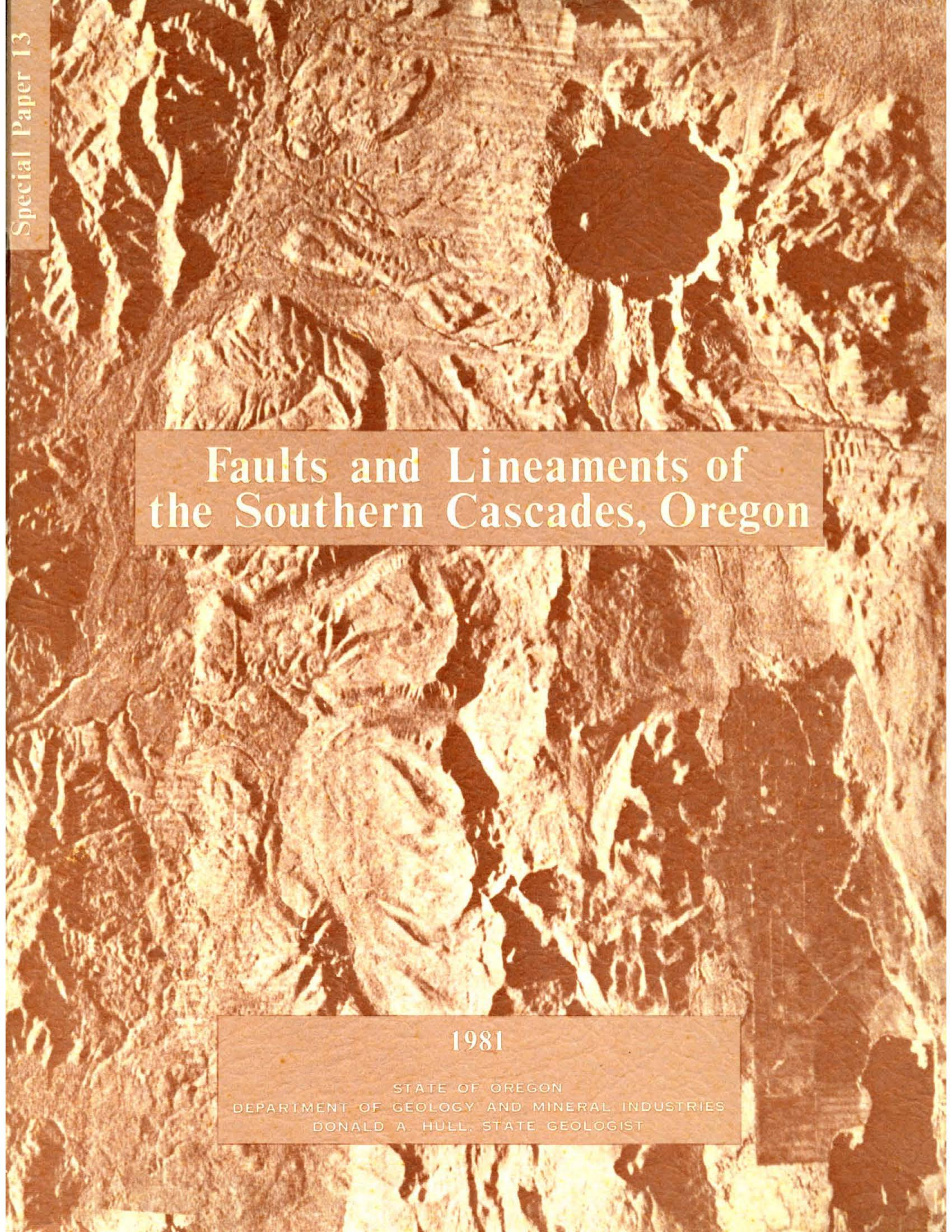


Special Paper 13

Faults and Lineaments of the Southern Cascades, Oregon

1981

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

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1005 State Office Building, Portland, Oregon 97201

Faults and Lineaments of the Southern Cascades, Oregon

SPECIAL PAPER 13

Principal Authors

C.F. Kienle
C.A. Nelson
R.D. Lawrence

FOUNDATION SCIENCES, INC.

Portland, Oregon
1981

Conducted in conformance with ORS 516.030
Funded in part under U.S. Department of Energy Contract DE-FC 07-79 ID-12044
to the Oregon Department of Geology and Mineral Industries

CONTENTS

ILLUSTRATIONS

COVER PHOTO:
Segment of SLAR imagery mosiac, Southern Cascades area

NOTICE

The Oregon Department of Geology and Mineral Industries is publishing this paper because the subject matter is consistent with the mission of the Department. To facilitate timely distribution of information, camera-ready copy submitted by the authors has not been edited by the staff of the Oregon Department of Geology and Mineral Industries.

Faults and Lineaments of the Southern Cascades, Oregon

PURPOSE AND SCOPE

This project was undertaken by Foundation Sciences, Inc. of Portland, Oregon, to complete the Oregon Department of Geology and Mineral Industries' lineament map series of the Cascade Range of Oregon (Figure 1). The objective was to construct a fault and lineament map of the Southern Cascades, from 121^{o} 30'W to 123^{o}W longitude, and 42^{o}N to 43^{o} 45'N latitude, based on interpretive study of the available high- and low-level imagery. This map (Plates 1 and 2) includes previously known and inferred faults, and identifies several extensions of known faults, several faults newly inferred during this study, and lineaments of unknown but probable structural origin. This report and accompanying map describe imagery types used, procedures used in interpreting the imagery, criteria used to identify lineaments, and the geologic influences in expression of lineaments and faults. Included is a brief tectonic interpretation of faults and lineaments in the study area.

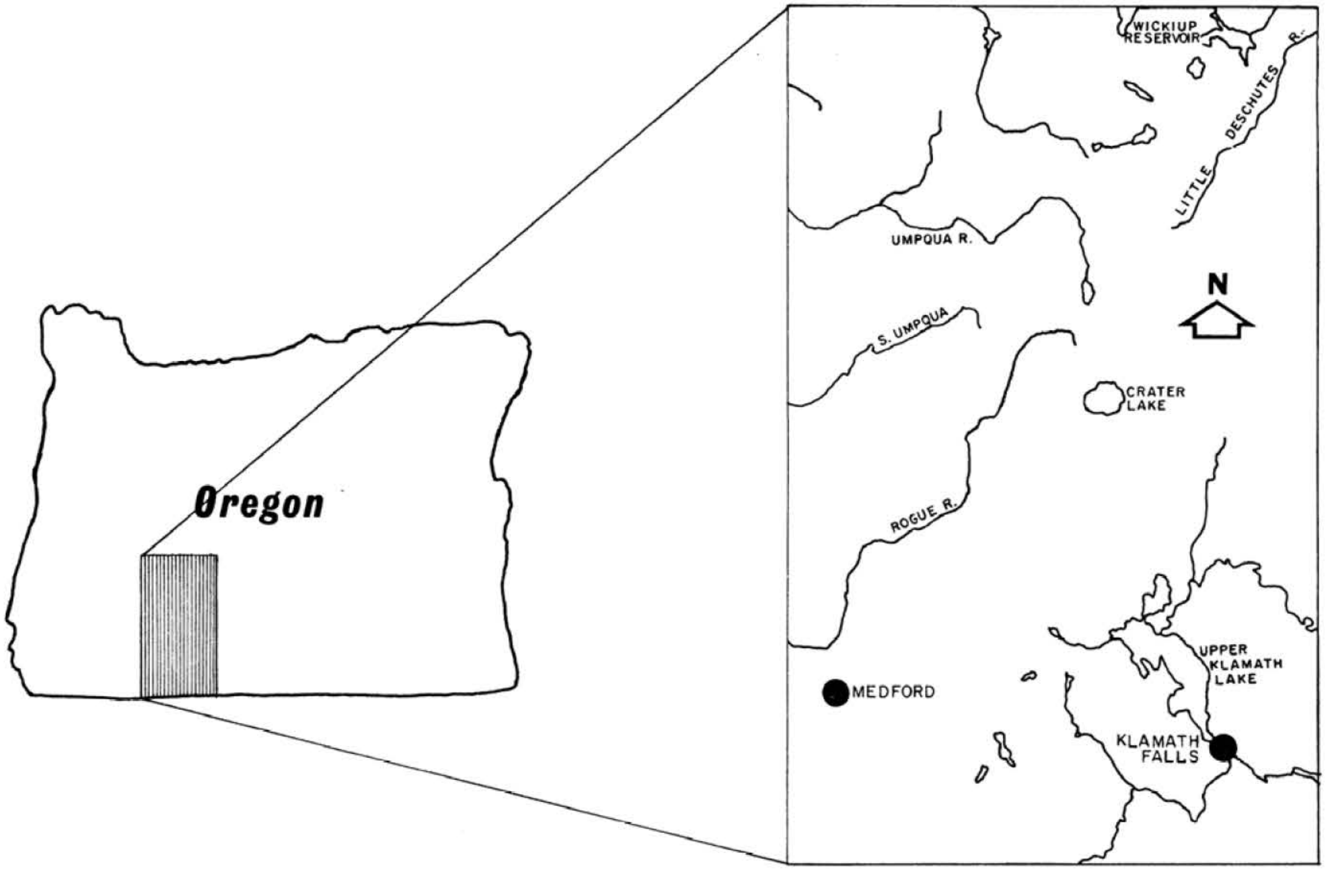


Figure 1. Location Map of Southern Cascades Project Area.

LOCATION AND SETTING

The study area is located in southwest central Oregon, centered on the Southern Cascades. The area is transected in a north-south direction by the volcanic peaks of the High Cascades, including Crater Lake (Mt. Mazama), Mt. Thielsen and Mt. McLoughlin. The Three Sisters Mountains lie approximately 50 km north of the study area. The area incorporates approximately 24,000 km^2 from the California border (42°N) north to latitude 43°45'N. The eastern boundary lies within the Basin-Range physiographic province at 121°30'W, and the western boundary, transecting the Klamath and Western Cascade physiographic provinces, lies at 123°W (Figure 2).

The area is generally mountainous and rural, much of it lying within the Umpqua, Willamette, Deschutes, and Winema National Forests. As a reference point, in the center of this region is Crater Lake National Park. The few major population centers, Medford, Ashland, and Klamath Falls, Oregon, are located in the southern section.

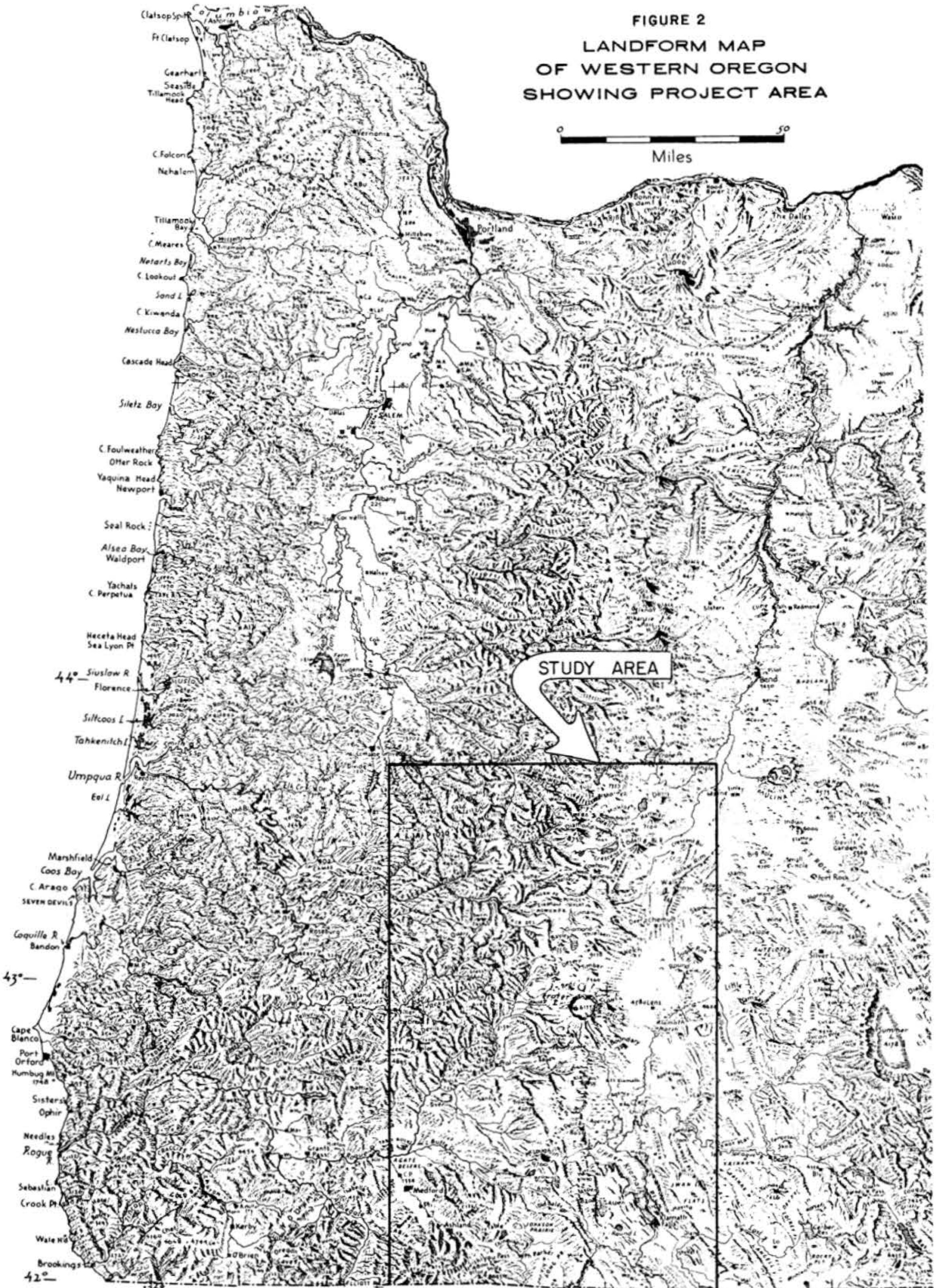
The prominent elevation of the north-south trending Cascade summit results in the climatic situation known as a "rain-shadow". An annual average of approximately 150cm of rain falls on the western side of the Cascades due to the uplift and subsequent cooling of air masses in contact with the mountain ranges. Little residual moisture remains in the air masses after crossing the Cascade summit. Consequently, the eastern side of the summit within the project area receives only about 50cm of precipitation annually.

In contrast to the generally mountainous western section of the study area, the area east of the Cascade summit is relatively flat, grading from the Cascade foothills to the flatland areas marking the western edge of the Basin-Range physiographic province.

The highest, most spectacular features within the area are the recently formed High Cascades, whose basalt and pyroclastic flows have covered much of the original topography to the east in the relatively flat Basin and Range province. To the west are the older, more eroded mountains of the Western Cascades, whose summits lie well below those of the major High Cascade peaks. The rugged, relatively low-lying Klamath Mountains in the southwest corner of the project area represent some of the oldest rock formations in Oregon.

Major drainage systems within the project area include the headwaters of the Willamette and Deschutes Rivers, the North and South Forks of the Umpqua River, and the Rogue River (Figure 1). Other major water bodies include the Upper Klamath, Agency, and Crater Lakes in the south, the Wickiup Reservoir, and Odell and Crescent Lakes in the north.

FIGURE 2
LANDFORM MAP
OF WESTERN OREGON
SHOWING PROJECT AREA



ORIGINAL MAP BY ERWIN RAISZ

TYPES AND USES OF IMAGERY IN LINEAMENT MAPPING

A variety of imagery is available for the study area in the Southern Cascades of Oregon. Three types were of principal utility in this study, which is concerned with lineament detection and delineation. Parts of the area are covered by side-looking airborne radar (SLAR) imagery (Figure 3). All of the area is covered by Landsat multispectral scanner (MSS) imagery (Figure 4). The entire area is also covered by about 90 frames of U-2 high-flight imagery flown by high-altitude reconnaissance aircraft (Figure 5). Other kinds of imagery are available for part or all of the area, such as low-altitude aircraft panchromatic photographs and thermal imagery, but these are not of particular value in lineament studies.

SLAR imagery portrays the area using low-angle radar illumination, which emphasizes linear topographic elements. The very low illumination angle means that deep shadows are present on the imagery where topographic relief is large, and some interpretation detail is lost in these shadows. The direction of illumination, or look direction, is perpendicular to the line of flight of the aircraft emitting and receiving the radar electromagnetic radiation. Thus, lineaments will be clearly portrayed if they are parallel or subparallel to the flight line but will become increasingly obscure as they become oriented more nearly at right angles to the line of flight. For this reason, it is very desirable to have several look directions for any particular study area. SLAR imagery is small scale and thus emphasizes the longer and more prominent lineaments, which are often, but not always, the most significant geologically. SLAR imagery is produced as long strips parallel to the flight line which are combined as a mosaic to give an overall view. Topographic detail is visible on this mosaic because of the shadows in the imagery. No stereo model is available. For this study, east and west looks were available in mosaics of part of the area by Motorola, 1974 (Figure 3). A north-looking strip crossing the southern part of the area was also available from NASA, 1973. Approximately 50% of the area was covered by SLAR imagery.

Landsat imagery is obtained from a satellite in an orbit about 90 km above the earth's surface. Individual measurements of reflectance in four different wavelength bands are computer-combined to provide four photographic images of the area. Two of these are for visible light and two are for near-infrared (not thermal) radiation. These can be combined in various ways to produce color imagery. The most common color rendition is a false-color infrared reconstitution. Interaction of the shorter wave length Landsat radiation with earth materials and vegetation is subtly different from that of radar radiation, so that slightly different features are emphasized. Like radar, topographic information is mainly the result of the low angle of illumination. This angle varies from moderate for summer imagery to low for winter imagery. More information is obtained by examining imagery from several dates than from examining a single frame. Like the radar imagery, Landsat is synoptic; that is, it covers a large area at small scale (usually 1:1,000,000 or 1:500,000.) Each scene has a nominal width of 185 km. Since the study area is covered on portions of three scenes (Figure 4) with considerable overlap in the east-west direction, Landsat does not have the distraction of frequent mosaic boundaries as on the SLAR mosaics. The illumination direction of the Landsat imagery is from the southeast, which differs from that of the SLAR and thus assists in investigating lineaments. Like the SLAR imagery, Landsat imagery is best at distinguishing long, prominent lineaments. Because of the differences between the imagery types, some different lineaments will show up on each kind of imagery, but they will normally be of similar scale and magnitude.

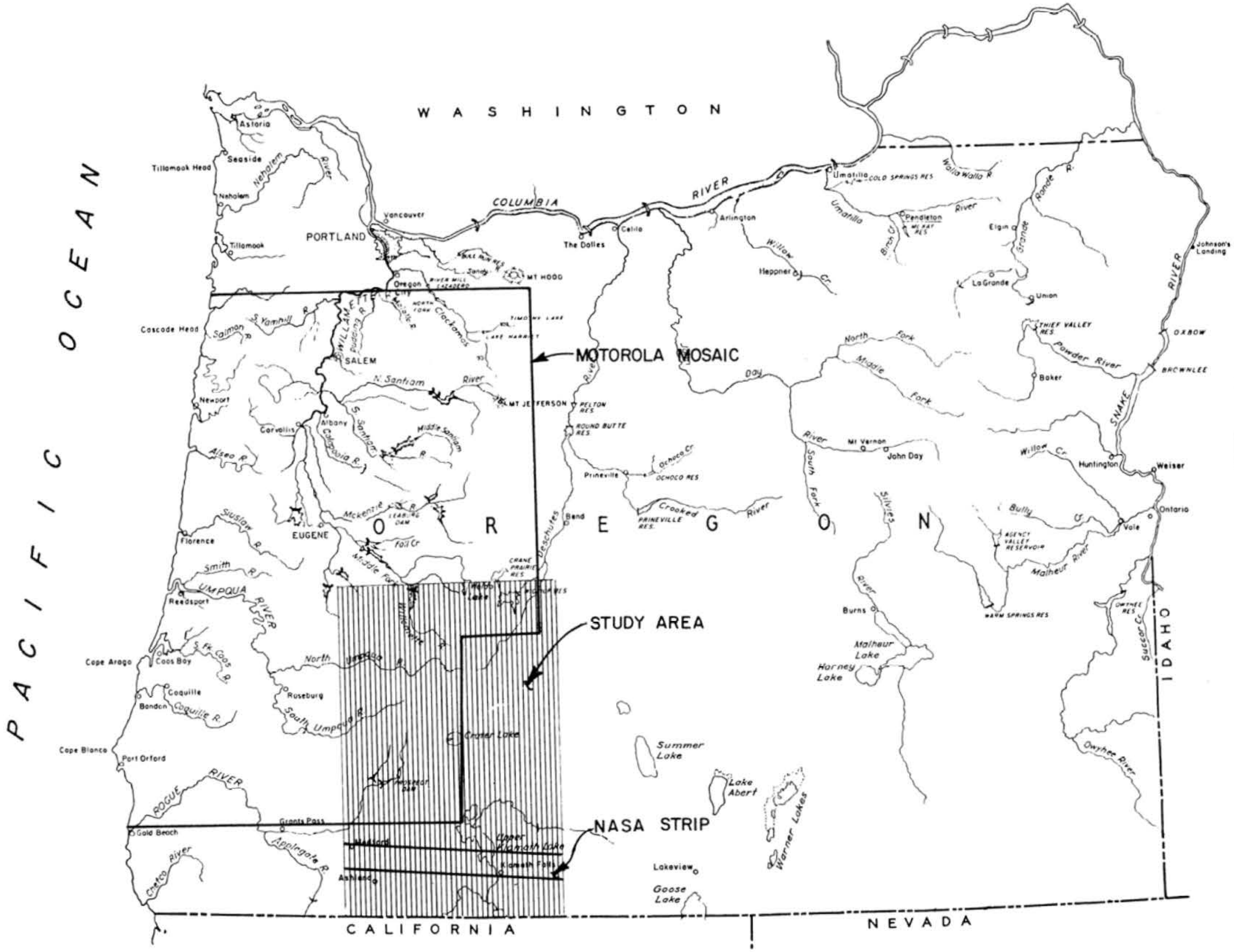


Figure 3. SLAR Coverage of South Cascades.

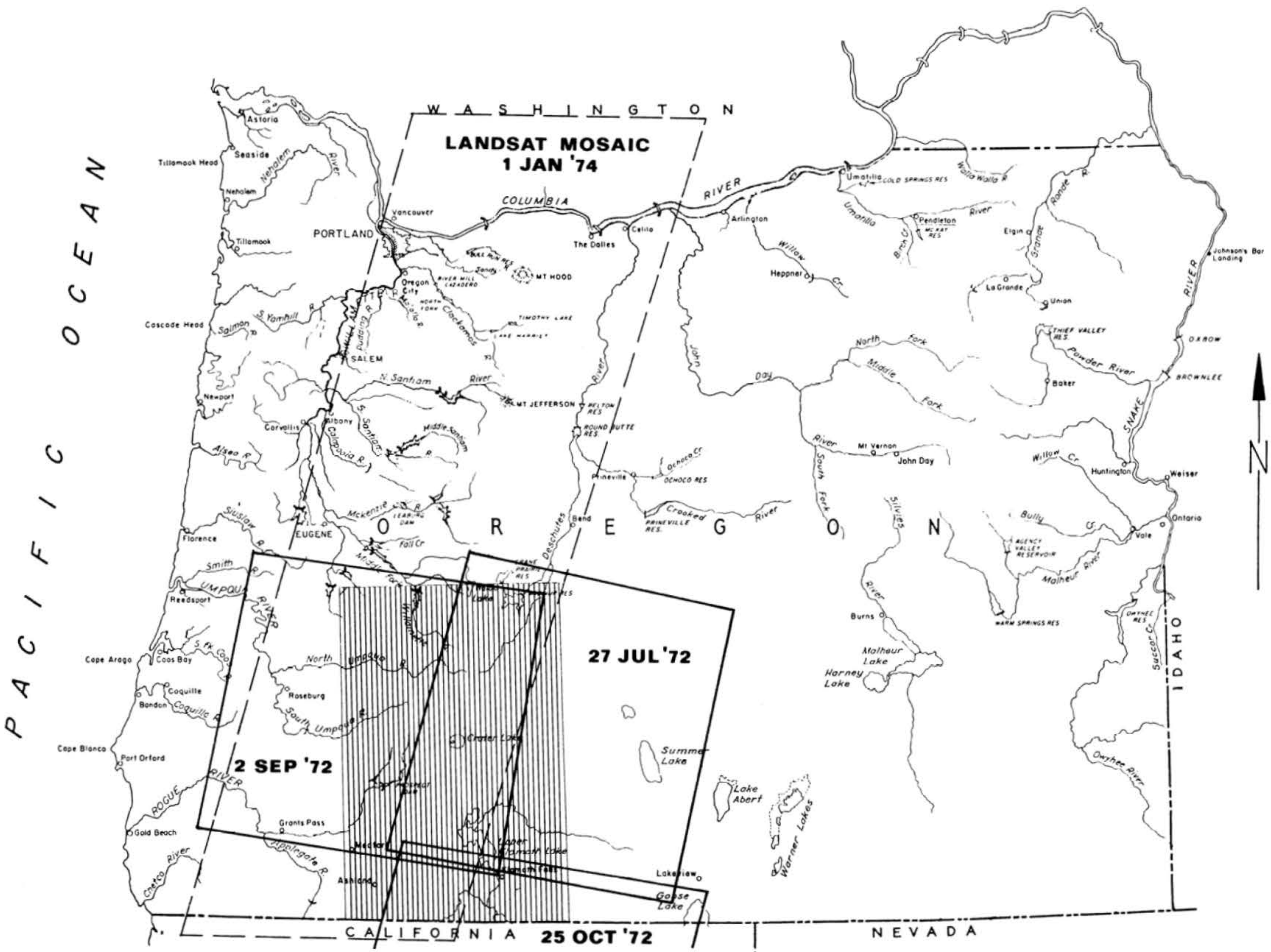


Figure 4. Landsat (ERTS) Coverage of Southern Cascades Project Area (shaded).

1100 through 1200 Series
from Flight #74-115
3 JUL 1974
NASA Accession #01849

900 Series
from Flight #74-110A
28 JUL 1974
NASA Accession #01837

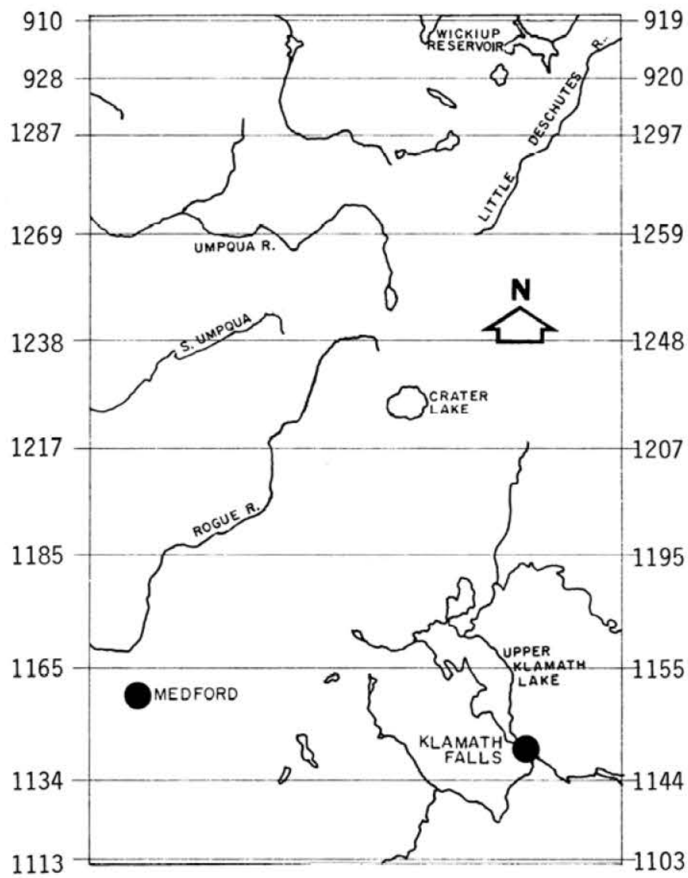


Figure 5. Flight Lines - U-2
False Color Infrared Imagery
of South Cascades.

The U-2 high flight imagery (Figure 5) is different from the SLAR and Landsat material in that it is not synoptic but rather is of large scale, suited to the detailed study of local features. It can be studied in stereo model. The imagery used in this study was flown in 1974 from high-altitude U-2 aircraft. The imagery is a true photographic product from false-color infrared film and is in transparency format. It serves as an underflight for detailed evaluation of the results of study of the synoptic imagery types. Numerous short lineaments can be detected that are not significant on the synoptic imagery. However, long lineaments will cross multiple frame (about 90 frames for this study area) and thus may not be detected unless previously found on synoptic imagery. The detailed configuration of long lineaments may be studied on this imagery. Often what appear as single linear features on synoptic imagery are found to be complex multiple-stranded features on U-2 imagery.

PROCEDURES USED IN LINEAMENT MAPPING

For this study, lineaments have been defined as linear or near-linear features visible on various imagery sources which can be demonstrated or reasonably interpreted to be related to the geology of the study area. The following characteristics were used as guides for identifying lineaments on the imagery:

1. Landform expressions - linear ridges or valleys; aligned saddles or breaks in slope; cross drainage alignments.

2. Drainage pattern expressions - linear or aligned streams or stream segments; abrupt, irregular changes in stream direction.

3. Abrupt changes in vegetation characteristics - indicating a natural boundary, change in surface characteristics, or vegetation community composition, also linear vegetation patterns.

4. Changes in surface texture or patterns expressed on imagery indicating a change in surface/subsurface characteristics.

5. Changes in tonal contrasts - linear contrast between dark and light tonal areas indicating a natural boundary or change in surface characteristics.

The extent that such lineaments represent geologically significant surface features, i.e., faults, joints, fractures, was determined by further evaluation. This interpretive evaluation initially involved an understanding of the regional geology and the regional characteristics which enhance or diminish surface expression of geologic features.

The features and details available from topographic and geologic maps, such as alignment of springs, stream beds, subtle changes in topography and zones of contact, are used as guides for determining the exact locations and geologic significance of linear structures. Relatively low level imagery sources afford a detailed view of surface features, and, when used in conjunction with appropriate maps, allow a high level of confidence in the placement and evaluation of lineaments.

As mentioned previously, the primary data sources for the construction of the accompanying lineament maps were SLAR imagery, Landsat imagery, and high-level U-2 infrared imagery. Complete coverage for the project area was provided by Landsat and U-2 imagery (Figures 4 and 5). East- and west-look SLAR coverage was available for only a portion of the area (Figure 3). Consequently, linear features derived from any one data source could be checked with at least one other imagery source, as well as the topographic maps.

The initial approach was to study the more synoptic coverage provided by Landsat imagery. Lineaments were transferred initially to 15-minute topographic maps and color-coded to reflect their source.

The relative lack of topographic detail provided by the 1:1,000,000 Landsat imagery required strict attention to locations of extracted lineaments when transferring them to 15-minute topographic sheets. However, this imagery allowed for the exclusion of small details which often obscure the continuity of the more extensive faults.

Use of SLAR imagery was approached in much the same way. Due to the inherent shadowing effects of the SLAR technique, much of the topographic detail is lost. This was partially compensated for by using two opposing (east- and west-look) SLAR images. These tend to emphasize the linear topographic elements, and, due to the relatively small scale, the longer, more prominent linear features are the most apparent.

Color-coded SLAR lineaments were transferred to 15-minute topographic maps; again, as with Landsat, close attention was given to proper placement with respect to corresponding surface features expressed on the contour maps.

Where possible, SLAR and Landsat imagery were studied concurrently with the topography to ensure proper location and extent of extracted linear features. The majority of the lineaments appeared either wholly, or in part, on both sets of imagery. On the final map, each lineament was shown according to the imagery which yielded the most prominent or accurate expression of the lineament.

The U-2 imagery was studied in stereoscopic view and yielded a significant number of shorter, less prominent linear features which were not found on the other imagery. Although the relatively small area covered by each U-2 frame precluded the identification of extensive linear features, it afforded a much more detailed view of the ground surface. This served as a final check on the accurate placement of lineaments derived from SLAR and Landsat imagery sources. This characteristic also provided an invaluable tool in determining the geologic significance of the linear features derived from other smaller-scale imagery sources.

The U-2 imagery proved particularly useful in the southern section of the study area, where vegetative ground cover is less dense and of different composition than in the northern areas. Many more lineaments were revealed in the southern section from U-2 flights, whereas in the northern section, interpretation of U-2 and SLAR imagery yielded much the same results in terms of identification of geologically significant lineaments.

Fifteen-minute topographic sheets (1:62,500 scale) were used as a basis for lineament evaluation in most of the area. In the northeast corner of the area (east of 122°W and north of 43°N), 7-1/2 minute (1:24,000 scale) maps were used. Lineament evaluation was facilitated by the use of the more detailed U-2 imagery, as well as comparisons with surface features as expressed on the contour maps. Mapped lineaments were checked against existing geologic maps to determine their relationship, if any, to known faults and local geologic structure. Those lineaments which were determined to be of geologic significance were checked by a second member of the project team to ensure accurate placement.

A significant number of linear or near-linear features were recognized from the contour line configurations on the topographic maps themselves. These are referred to as "topo-lineaments" on Plates 1 and 2. In some sections of the study area, the maps proved to be the most productive and accurate source of lineaments. This was especially true in the northeast corner of the study area, where all work was performed on the more detailed 7-1/2 minute topographic maps. The relatively large scale of the stereoscopically viewed U-2 imagery also proved valuable in this area, especially for siting shorter lineaments and confirming lineament locations within the context of the large, 7-1/2 minute topographic sheets. The smaller-scale format of SLAR and ERTS imagery allowed us to discern the more extensive lineaments in this area which transect a number of topographic sheets and do not reveal themselves as readily on either the 7-1/2 minute maps or the U-2 frames.

The majority of the project area, covered by 15-minute topographic maps, was studied most productively through SLAR and U-2 imagery. Though topo-lineaments were noted in some areas, the smaller scale of these contour sheets obscured the topographic details necessary for extensive topo-lineament extraction as on the 7-1/2 minute quad sheets. Topographic maps and U-2 imagery revealed the shorter lineaments, while the SLAR and ERTS imagery allowed for a clearer, less fragmented view of the longer lineaments which extend across a number of topographic sheets. The continuity of the longer lineaments is often obscured by the high degree of detail found on U-2 imagery and the topographic maps and reveals itself best on the more synoptic coverage provided by Landsat or SLAR.

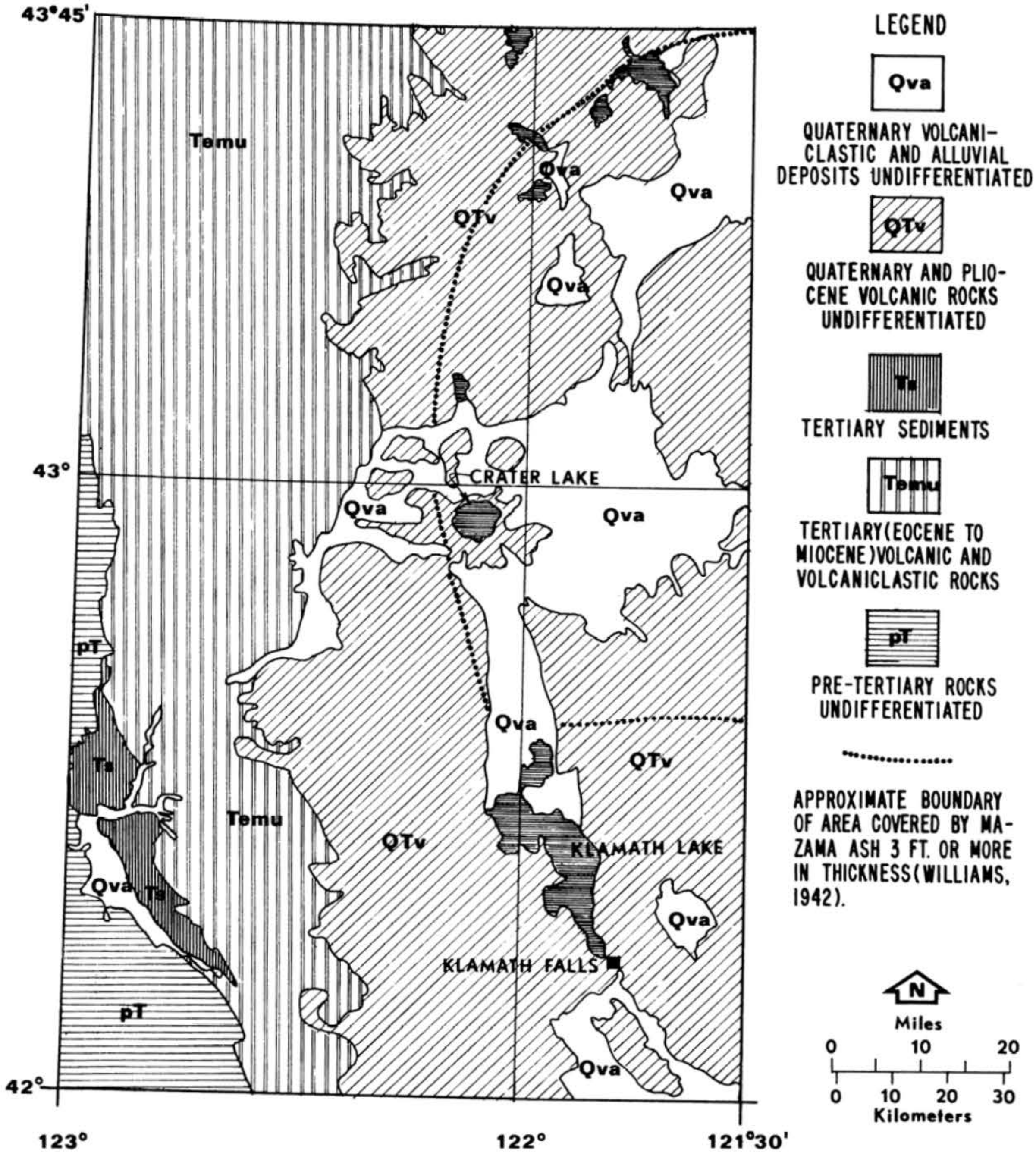


FIGURE 6. GENERALIZED GEOLOGIC MAP OF SOUTH CASCADES

GEOLOGIC CONTROL OF THE EXPRESSION OF FAULTS AND LINEAMENTS

Faults within the study area have different expressions in different parts of the area, controlled to a large extent by the type and age of the terrain which they cut, and by the age, type and offset of the faults. Structural expression is also influenced by the amount of rainfall, and, consequently, the differences in rate of erosion and amount of vegetation between the areas of high precipitation on and west of the Cascade Summit and areas of low precipitation to the east. For example, many of the young faults bounding the Klamath Graben in the east part of the area (Plate 2) have fresh-appearing, near-vertical scarps with heights approximately equaling the vertical offset. This is due to the youthfulness of the faults, the general competence of the bedrock and the low erosion rate in the generally dry climate.

Apparently youthful faults also occur in the northern part of the Klamath Graben (south of Crater Lake) and in the Walker Rim area further to the north. However, many of these structures are partially mantled by Mazama Ash, which covers most of the east-central part of the area (Figure 6). Similarly, great thicknesses of reworked Mazama Ash and/or Mazama pyroclastic deposits fill the upper Rogue River, Diamond Lake Basin, upper Klamath Lake Basin, Antelope Desert, and Klamath Marsh, effectively burying features which predate the Mazama eruption (7000 B.P.). These areas are shown on Figure 6 as areas of "Qva" which surround Crater Lake. Only a few subtle linear features cross these buried areas (Plates 1 and 2).

Fresh, generally linear fault groups also occur in the High Cascades, particularly south-southwest of Crater Lake where Mazama Ash is thin or absent (Plate 2). Most of these faults strike north-south and appear to have offsets of no more than about 10 meters. Thus, the thick Mazama Ash cover north of Crater Lake could easily hide similar faults.

The few faults previously mapped in the Western Cascades are generally less well expressed than those in areas to the east. Indeed, only a few new faults were inferred in the Western Cascades during this study because of the difficulty of interpretation in this complex terrain. Most mapped faults in the Western Cascades have linear expressions; these expressions are generally eroded fault line scarps, drainage alignments, aligned cross-drainage notches, or rarely, linear ridges. Generally thick vegetation and soil cover mask fine details. Thus, motions on inferred faults in this part of the area are tentative and need confirmation from field mapping.

Similar problems of interpretation occur in the small segment of pre-Tertiary rocks exposed in the southwest part of the area (Figure 6). Previous mapping in this highly-dissected, structurally complex area has demonstrated a strong northeast to north-northeast structural grain (e.g. Wells and Peck, 1961), parallel to the regional strike of bedding. However, the most prominent lineaments (Plate 2) strike perpendicularly or obliquely to this grain. As in the Western Cascades, most known or inferred faults are linear or near-linear and are expressed as secondary topographic features. It is likely that most of the lineaments shown in the pre-Tertiary rocks on Plate 2 are faults. However, their relationship to mapped faults and their offset, age, and structural significance remain unknown; thus, no lineaments in pre-Tertiary rocks are shown as newly-inferred faults on Plate 2.

The expressions of lineaments in the study area can be roughly divided into two types. First are those in the youthful Basin and Range (Klamath Graben and Walker Rim areas) and the eastern High Cascades terrains. In these two areas, lineaments are generally the expression of a primary structural control on topography. Examples include both faults and alignments of various volcanic centers. Outside areas covered by thick

Mazama Ash or alluvium (Figure 6), nearly all lineaments can be seen to be a result of one (or rarely both) of these structural controls. Thus, the ratio of faults and inferred faults to lineaments of unknown origin is high in these two terrains, and our confidence in the fault offsets is similarly high.

In the Western Cascades and the west part of the High Cascades, the known and inferred faults are outnumbered by lineaments of unknown origin. In part, the small number of lineaments inferred to be faults may be due to an actual paucity of faults in comparison to areas to the east, especially in the High Cascades where the rocks are quite young (Quaternary and Holocene). However, lack of inferred faults in these areas is thought to be largely the result of our reluctance to infer faulting on lineaments where direct evidence of displacement is lacking, even though they appear to be structurally controlled. We have inferred faults only along lineaments where strong evidence for faulting can be seen on the available imagery or topography. Stratigraphic or primary topographic offset, distinct textural contrasts, or truncation of known structures are examples of the type of evidence used to infer faults. Thus, many lineaments which occur in the Western Cascades are probably faults which can be confirmed only by careful field mapping.

Two areas in particular which contain many lineaments which are probably faults are the N55^{o}W- to N60^{o}W- trending Eugene-Denio and Mt. McLoughlin fault zones discussed below. Both these zones consist of many parallel or en echelon, right-lateral strike-slip faults in south-central Oregon, northeast California, and northwest Nevada (Lawrence, 1976).

TECTONIC INTERPRETATION

The east portion of the study area includes the west margin of the Basin and Range tectonic province and the southern Oregon part of the High Cascades Range (Figure 7). Frequent small, but unlocated, earthquakes in the Klamath Falls area (R.W. Couch, personal communication, 1981) and recent volcanic activity in several parts of the High Cascades demonstrate that both of these youthful-appearing areas are indeed loci of present day tectonism. As discussed below, results of this investigation suggest an interaction between these two active areas south of Crater Lake, where the northwest-striking Basin and Range faulting appears to merge into the north-south trend of the High Cascades (Plate 1).

The western part of the study area is dominated by the southern portion of the Western Cascades (Figure 7). Volcanic and volcaniclastic rocks in this north-trending belt (Figure 6) record a long and complex history of marginal arc deformation and volcanism (Armstrong, 1978; White and McBirney, 1978), presumably a consequence of Eocene through Miocene subduction of the Juan de Fuca Plate beneath western North America (Atwater, 1970). Regionally, the rocks of the Western Cascades dip eastwards beneath the High Cascades. The limited occurrences of pre-Tertiary rocks in the southwest part of the area record an even more complex tectonic history whose details are still not known. This eastern part of the Klamath Mountains is in part overlapped by younger rocks of the Western Cascades (Wells and Peck, 1961), but both northwest- and northeast-striking structures offset the terrain. Although the Klamath Mountains and the Western Cascades are underlain by quite distinctive rock types and have quite different origins, they appear to have responded similary to the late Tertiary interactions between the North American and the Juan de Fuca Plates (Atwater, 1970). Thus, they presently appear to be part of one tectonic province (Pacific Border?) in spite of their earlier differences.

Faults and lineaments shown on Plates 1 and 2 in the Southern Cascades study area have orientations which box the compass. However, the majority fall into three groups with strikes to the northeast, northwest or north. Superficially, these three groups appear compatible with either the east-west extensional tectonism of the Basin-Range or the north-south compressional stress regime postulated for most of the Pacific Northwest to the north and west of the Basin-Range Province (e.g. Smith, 1978; Kienle and Couch, 1977; Kienle and others, 1980; Venkatakrishnan and others, 1980). Either north-south compression or east-west extension could produce a pattern of north-south normal faults and northwest and/or northeast striking oblique or strike-slip faults, with resulting east-west crustal extension. However, closer examination of lineament trends and strikes of faults in the area reveals that the three immediately observable groups of directions are not uniformly distributed throughout different structural domains in the South Cascades (Plates 1 and 2). Furthermore, in some areas both the northwest- and northeast-striking groups contain two distinct sets of faults and/or lineaments orientations which do not overlap. In addition, generally east-west features, while rare, do occur locally in the Western Cascades. These lineament sets were defined by inspection of the imagery. Rose diagrams of the area are not included in this report, nor are they necessary to document the distinctive sets shown on Plates 1 and 2. Rose diagrams were constructed for some parts of the area. However, they appeared to us to illustrate the bias of the data base (i.e, SLAR flight-time directions, topographic map scale) better than they illustrate the readily observable lineament sets.

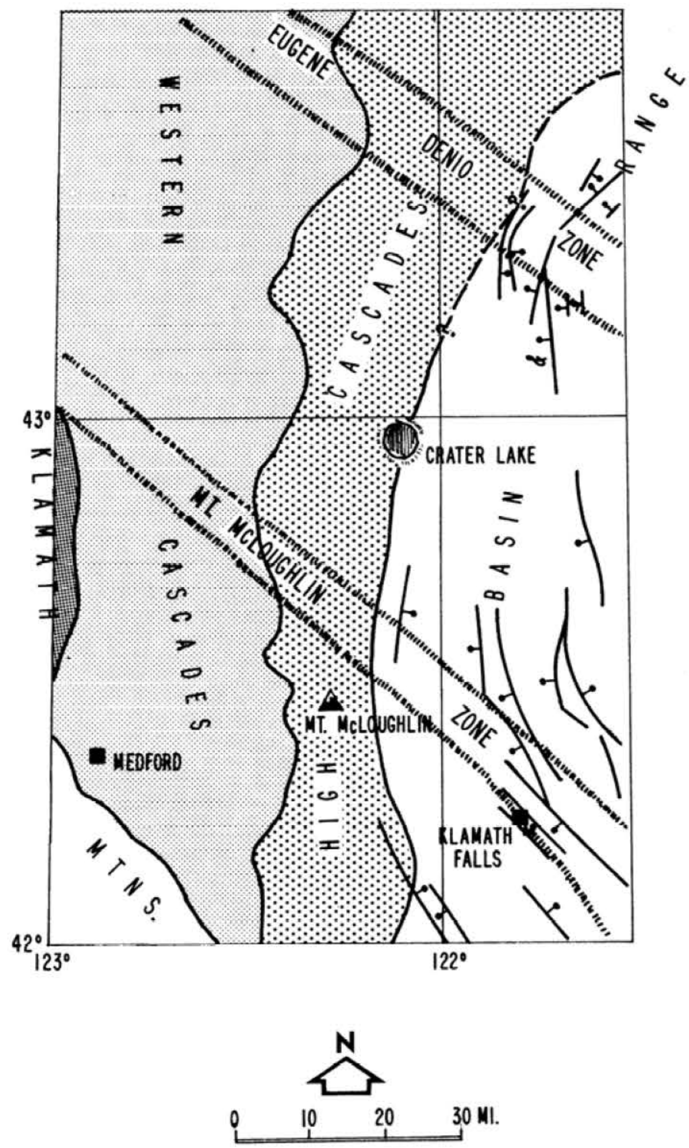


FIGURE 7. TECTONIC PROVINCES AND MAJOR FAULT ZONES—SOUTH CASCADES AREA.

Basin and Range

Basin and Range structures extend into the east part of the area. The Klamath Graben is the easternmost extent of the late Cenozoic, generally northwest to north-south striking extensional faulting which forms the fault block mountains and basins from which the province takes its name. As a whole, the Basin and Range Province extends from southeast Oregon and southern Idaho through northeast and southeast California, Nevada, western Utah and western Arizona into Mexico. For an extensive analysis of the province, the reader is referred to Stewart (1978).

Within the study area the Basin and Range is subdivided into three distinct sections based on the trend, pattern, and possibly the age of faulting. The parts are separated by northwest striking zones of right-lateral shear which extend both southeast and northwest of the area. These two zones, the Eugene-Denio (E-D) and Mt. McLoughlin (MM) fault zones (Figure 7) were first noted by Lawrence (1976). Together with the Vale and Brothers fault zones to the northeast, they are postulated to form the northern boundary of the Basin and Range Province (Lawrence, 1976; Stewart, 1978). The difference between the east-west crustal extension of the Basin and Range and non-extended areas to the north appears to be accomodated by the cumulative right-slip across these fault zones (Lawrence, 1976).

In the part of the Basin and Range south of the MM zone, extending from Mr. McLoughlin through Klamath Falls, the majority of Basin and Range faults strike northwest (N35^{o} to N50^{o}W) where they impinge on the east flank of the High Cascades (Plate 1). A few faults with more westerly strikes (N55^{o}W to N65^{o}W) branch from, or connect, sets of the N35^{o}W to N50^{o}W striking faults in an interlocking rhombic or reticulate pattern similar to that described by Donath (1962) in the Summer Lake area. This pattern of faulting terminates at the MM zone.

The northwest (N30^{o}W to N50^{o}W) faults continue into the MM zone but die out a few kilometers to the north. The west-northwest (N55^{o}W to 65^{o}W) faults which nearly parallel the MM zone are particularly well expressed within it (Plate 2) and do not occur to the north. The MM zone is also well expressed southeast and northwest of the study area as a 15 to 20 km-wide band of lineaments and faults (Lawrence, 1976). Within the study area, the best expression of the MM zone is the sharp change in orientation of the Basin and Range faults across it.

The central part of the Basin and Range within the study area is bounded by the MM zone on the southwest and the Eugene-Denio (E-D) zone on the northeast. From Lake of the Woods northward to Crater Lake, a series of generally north-striking (N25^{o}E to N25^{o}W) down-to-the-west faults forms the mutual boundary between the High Cascades and the Basin and Range. Between Crater Lake and the E-D zone, this boundary is masked by thick Mazama Ash (Figure 6); however, an inferred fault along the west side of Diamond Lake may represent its continuation northwards to the E-D zone.

As noted, Basin and Range Faults between the E-D and MM zones strike more northerly than those south of the MM zone. At the west part of this area, the faults largely parallel the north-south trend of the High Cascades. Farther to the east, most Basin and Range faults strike between north and N35^{o}W and are predominantly down to the west. A few well-expressed east to east-northeast (ENE) striking faults are nearly perpendicular to north-northeast (NNE) faults. Most such E to ENE faults are in, or near, either the MM or E-D zones (Plate 2). Sets of faults with this strike near the MM zone occur at Lather Mountain, northwest of Agency Lake and in the E-D zone east of Klamath Marsh.

In, and north of, the Eugene-Denio (E-D) zone, Basin and Range faults swing to a generally northeast strike (N35^{o}E to N55^{o}E). A few more northerly striking faults in the

E-D zone near the Chemult and Walker Mountain areas appear to be transitional between north-northwest (NNW) striking faults south of the E-D zone and NE striking faults to the north. Accompanying the pronounced change in strike of the Basin and Range faulting is a marked narrowing of its east-west extent. South of the E-D zone, Basin and Range structures form a graben which extends over 40 km from west of Crater Lake to east of Klamath Marsh. At the E-D zone, the graben is 20 to 25 km wide. It appears to maintain this width to the northeast corner of the study area, although with decreasing structural relief. Interestingly, this graben and lineaments parallel to it trend towards Newberry Crater, disappearing beneath the young flows and tephra of the volcano's flanks.

In summary, Basin and Range faulting enters the area from the southeast as the broad, 40-km-wide Klamath Graben. The graben narrows northwards, and strikes of the principal graben-bounding faults rotate clockwise from NW to NE. Most of the rotation of strike and narrowing occur across, or in, two major discontinuities - the NW-striking Mt. McLoughlin (MM) and Eugene-Denio (E-D) fault zones.

Another change in faulting apparently takes place across the MM and E-D zones. North of the E-D zone, all fault scarps are geomorphically youthful; this is particularly evident where movement has been of sufficient magnitude, or scarps are steep enough, to have escaped burial by the 7,000-year-old Mazama Ash or subsequent aeolian reworking of the ash. Between the E-D and MM zones, many fresh scarps are present, such as those near the periphery of the graben at Wocus Bay and south of Crater Lake. Faults closer to the center of the graben, however, are commonly less fresh in appearance, with erosion and recession of the scarps. South of the MM zone, fresh scarps are still present, particularly at the Basin and Range - Cascade boundary. However, eroded scarps and fault-line scarps are much more common (Lawrence, 1976).

The change from predominantly fresh-appearing fault scarps north of the E-D zone to less fresh scarps south of the zone was first noted by Lawrence (1976) and is consistent with an older age for the major faulting south of the E-D zone than to its north. Our present observations are consistent with Lawrence's (1976) age hypothesis and with Christiansen and McKee's (1978) interpretation that Basin and Range faulting propagated from south to north with time. The apparent concentration of young-appearing faults along the margins of all of the Basin and Range in the study area and the northward narrowing of the Klamath-Antelope Desert-Walker Rim Graben, however, suggest that propagation was both northwards <u>and</u> outwards, into the marginal areas. Continued seismicity in the area (R.W. Couch, personal communication, 1981) suggests that propagation of the Basin and Range may still be occurring.

High Cascades

The High Cascades comprise an approximately north-south belt of Pliocene, Pleistocene, and Holocene basaltic and andesitic volcanic centers which straddle the north-south axis of the study area (Figures 6 and 7). Locally, large andesite-dacite stratovolcanos occur along the eastern margin of the belt. Tectonically, the young volcanic rocks of the High Cascades are overlapped by the west margin of the Basin and Range Province, so that some major volcanic centers of the High Cascades actually sit within the Basin and Range. Examples include Pelican Butte and Crater Lake, which lie between the E-D and MM fault zones. Similarly, Newberry Crater, east of the study area, may lie on the northeast continuation of the Walker Rim Graben. When only Pleistocene and Holocene volcanic centers are considered, most south of the E-D zone lie either on the Basin and Range - Cascades boundary or within the Basin and Range tectonic province. Those few which lie farther to the west such as Mt. McLoughlin or Diamond Peak lie in either the MM or E-D zones (Plates 1 and 2).

In comparison to the Western Cascades to the west and the Basin and Range to the east, most of the High Cascades have very few lineaments. This is largely attributable to the extensive cover of young volcanic rocks and Mazama Ash. However, the lineaments and faults which are present are remarkably consistent in strike with those to the west where WNW, NNW, NNE and ENE are the dominant directions. In addition, north-striking lineaments and faults are abundant along the east boundary of the High Cascades. The WNW and NNW sets are concentrated in the E-D and MM zones. This concentration is particulary apparent for the longer lineaments (Plates 1 and 2).

Both the E-D and MM zones appear to offset the axis of High Cascade volcanism in a right-lateral sense (Lawrence, 1976). South of the MM zone, the westernmost Pleistocene-Holocene volcanic centers lie along a line extending south-southeast from Mr. McLoughlin. North of the MM zone, these centers extend along a line from west of Diamond Lake northward to Diamond Peak and southward past Crater Lake to Pelican Butte, about 16 km east of Mt. McLoughlin. North of the E-D zone, the westernmost Pleistocene to Holocene volcanic centers extend northwards from Maiden Peak, a few kilometers north of Odell Lake. They thus appear to be aligned about 15 km east of those to the south.

Lawrence (1976) hypothesized that the apparent offset of the High Cascade volcanic centers could provide a measure of the slip on the E-D and MM fault zones. An alternate hypothesis offered by Lawrence (1976) is that these two zones are pre-High Cascade features which have influenced the propagation of both Basin and Range structures and the location of young Cascade volcanos, which also appear to be affected by the Basin and Range structures.

Western Cascades

Faults and structurally related lineaments in the Western Cascades record deformation from Oligocene to at least Pliocene time. During this time span, changes occurred in the regional tectonics of the area as a result of changes in interaction between the North American and Juan de Fuca Plates (Baldwin, 1964). Any tectonic analysis of the complex Western Cascades area thus runs immediately into the problem of discriminating between features of different ages and different tectonic environments. Such a comprehensive analysis is beyond the scope of the present study.

Within the part of the Western Cascades investigated, five lineament sets occur. These are:

N55^{o}-65^{o}W (WNW)
N30^{o}-45^{o}W (NNW)
N5^{o}W-N5^{o}E (N)
N25^{o}-35^{o}E (NNE)
N60^{o}-70^{o}E (ENE)

Lineaments with other orientations occur; however most fall within or near these sets (Plates 1 and 2). Two zones within the Western Cascades show a preferred lineament orientation. The Eugene-Denio (E-D), and Mt. McLoughlin (MM) both contain a large proportion of the west-northwest (WNW) and NNW lineaments and faults. As mentioned previously, these two zones exhibit strong control on the structural pattern of the High Cascades and Basin and Range. Both zones continue WNW through the Western Cascades to the west boundary of the study area. However, the systematic changes observed across these zones east of the Western Cascades are not apparent within older rocks.

Venkatakrishnan and others (1980) proposed that lineament patterns in the Western Cascades north of the present study area resulted from north-south compression (N10°W ± 10°). The bimodal distribution of NW and NE striking faults and linears (i.e., into WNW, NNW, NNE and ENE sets) suggests to us, however, a more complex origin, possibly involving an older NNE oriented compressional episode followed by a younger (present day?) NS compressive event. Similar changes in stress orientation have been proposed for the central Basin and Range Province by Eaton and others (1978) and for the Columbia Plateau by Kienle and Couch (1977).

REFERENCES CITED

Armstrong, R.L., 1978, Cenozoic igneous history of the U.S. Cordillera from lat. 42° to 49°N, in Smith, R.B. and others, eds., Cenozoic tectonics and regional geophysics of the Western Cordillera: Geological Society of America Memoir 152, p. 265-282.

Atwater, T., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society of America Bulletin, v. 81, p. 3513-3535.

Baldwin, E.M., 1964, Geology of Oregon: Edwards Bros., Inc., Ann Arbor, Michigan, p. 169.

Bowen, R.G., and Peterson, N.V., 1970, Map of the state of Oregon showing thermal springs and wells: Oregon Department of Geology and Mineral Industries.

Bowen, R.G., Peterson, N.V. and Riccio, J.F., 1978, Low- to intermediate-temperature thermal springs and wells in Oregon: Oregon Department of Geology and Mineral Industries, GMS-10.

Christiansen, R.L. and McKee, E.H., 1978, Late Cenozoic volcanic and tectonic evolution of the Great Basin and Columbia intermontane region, 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. 283-312.

Donath, F.A., 1962, Analysis of basin-range structure, south-central Oregon: Geological Society of America Bulletin, v. 73, p. 1-15.

Eaton, G.P., Wahl, R.R., Prostka, H.J., Mabey, D.R., and Kleinkopf, M.D., 1978, Regional gravity and tectonic patterns: their relation to late Cenozoic epeirogeny and lateral spreading in the western Cordillera, in Smith, R.B. and Eaton, G.P., eds., 1978, Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 51-92.

Hardyman, R., McIntyre, J.R., and Richardson, L.K., 1972, Geologic map of the southern Klamath Basin: U.S. Geological Survey Open File Map.

Kienle, C.F., Jr., and Couch, R.W., 1977, Additional information on the seismicity and tectonics of the Columbia Plateau, Attachment 5: for Portland General Electric Company, Pebble Springs Nuclear Plant, 37 p.

Kienle, C.F., Jr., Hamill, M.L., Lite, K.E., and Peterson, G.L., 1980, Geologic reconnaissance of parts of the Walla Walla and Pullman, Washington, Pendleton, Oregon 1°x2° AMS quadrangles for U.S. Army Corps of Engineers Seattle District: 66 p.

Lawrence, R.D., 1976, Strike-slip faulting terminates the Basin and Range province in Oregon: Geological Society of America Bulletin, v. 87, p. 846-850.

Motorola Aerial Remote Sensing Inc., 1975, SLAR mosaic of southwestern Oregon: scale 1:250,000, semi-controlled mosaic.

National Aeronautic and Space Administration SLAR strip taken 25-57 October, 1965, Mission numbers APQ-96 and APQ-98.

Peck, D.L., Griggs, A.B., Schlicker, H.G., Wells, F.G., and Dole, H.M., 1964, Geology of the central and northern parts of the western Cascade Range in Oregon: U.S. Geological Survey Professional Paper 449, 56 p.

Peterson, N.V., and McIntyre, J.R., 1970, The reconnaissance geology and mineral resources of eastern Klamath County and western Lake County, Oregon: Oregon Department of Geology and Mineral Industries Bulletin 66, 70 p.

Raisz, E., 1965, Landforms of the northwestern states: Harvard University, one map.

Riccio, J.F., 1978, Preliminary geothermal resources map of Oregon: Oregon Department of Geology and Mineral Industries GMS-11.

Robison, J.H., 1972, Availability and quality of ground water in the Medford area, Jackson County, Oregon: U.S. Geological Survey Hydrologic Investigations Atlas HA-392.

Shannon and Wilson, Inc., 1974, Geotechnical studies for preliminary evaluation of a proposed nuclear power plant site at Calapooya (Sutherlin), Oregon: Report to Pacific Power and Light Company, Portland, Oregon, 86 p.

Smith, R.B., 1978, Seismicity, crustal structure, and interplate tectonics of the interior of the western Cordillera, in Smith, R.B. and Eaton, G.P., eds, 1978, Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 51-92.

Stewart, J.G., 1978, Basin-Range structure in western North America: A review, in Smith, R.B. and Eaton, G.P., eds., 1978, Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 51-92.

U.S. Army Corps of Engineers, 1980, Applegate Lake design memorandum #9, geologic foundation and embankment design, Supplement #2, earthquake and fault study, Klamath Falls and Medford Quadrangles tectonic maps.

Venkatakrishnan, R., Bond, J.G., and Kauffman, J.D., 1980, Geological linears of the northern part of the Cascade Range, Oregon Department of Geology and Mineral Industries Special Paper 12.

Wells, F.G., and Peck, D., 1961, Geologic map of Oregon west of the 121st meridian: U.S. Geological Survey Miscellaneous Investigation Map I-325, scale 1:500,000.

White, C.M., and McBirney, A.R., 1978, Some quantitative aspects of orogenic volcanism in the Oregon Cascades, in Smith, R.B. and Eaton, G.P., eds., 1978, Cenozoic tectonics and regional geophysics of the western Cordillera: Geological Society of America Memoir 152, p. 51-92.

Williams, H., 1942, The geology of Crater Lake National Park, Oregon: Carnegie Institution of Washington Publication 540, 162 p.

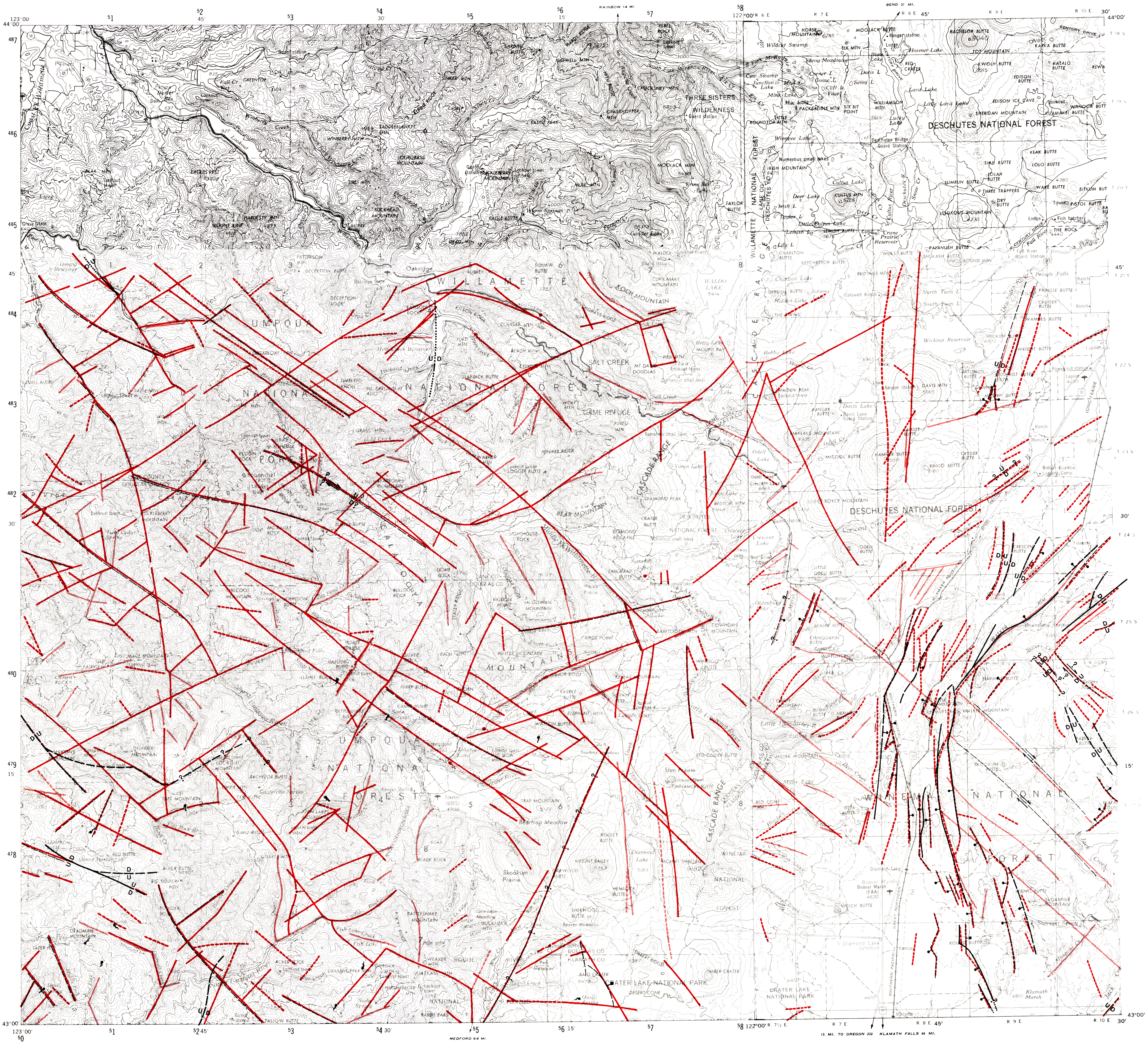
PLATE 1

SpP 13

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

Fault and Lineament Map of the Eastern Part of Roseburg and Western Part of Crescent – 1° x 2° AMS Quadrangles
1981

By C.A. Nelson, C.F. Kienle, R.D. Lawrence



Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

5 0 5 10 15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

KNOWN FAULTS COMPILED FROM:

Peck and others, 1964.

Riccio, 1978.

Shannon and Wilson, 1974.

Wells and Peck, 1961.

THERMAL SPRINGS DATA MODIFIED FROM:

Bowen and Peterson, 1970.

Bowen and others, 1978.

Riccio, 1978.

LINEAMENTS FROM:

Topographic map (USGS - 1:62,500 or 1:24,000 scale)

SLAR (Side Looking Airborn Radar - 1:250,000 scale)

ERTS (Earth Resources Technology Satellite - 1:500,000 scale)

U-2 flight imagery (1:125,000 scale)

GEOLOGIC SYMBOLS

KNOWN FAULTS.

FAULTS INFERRED FROM LINEAMENTS.

FAULTS: Solid where exposed, dashed where approximate, dotted where covered, queried where questionable.

U and D denote sense of apparent vertical offset.

Apparent dip slip; ball on downthrown side.

Strike Slip; parallel arrows indicate sense of slip.

Non-Thermal Springs with apparent structural control.

Thermal Springs

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

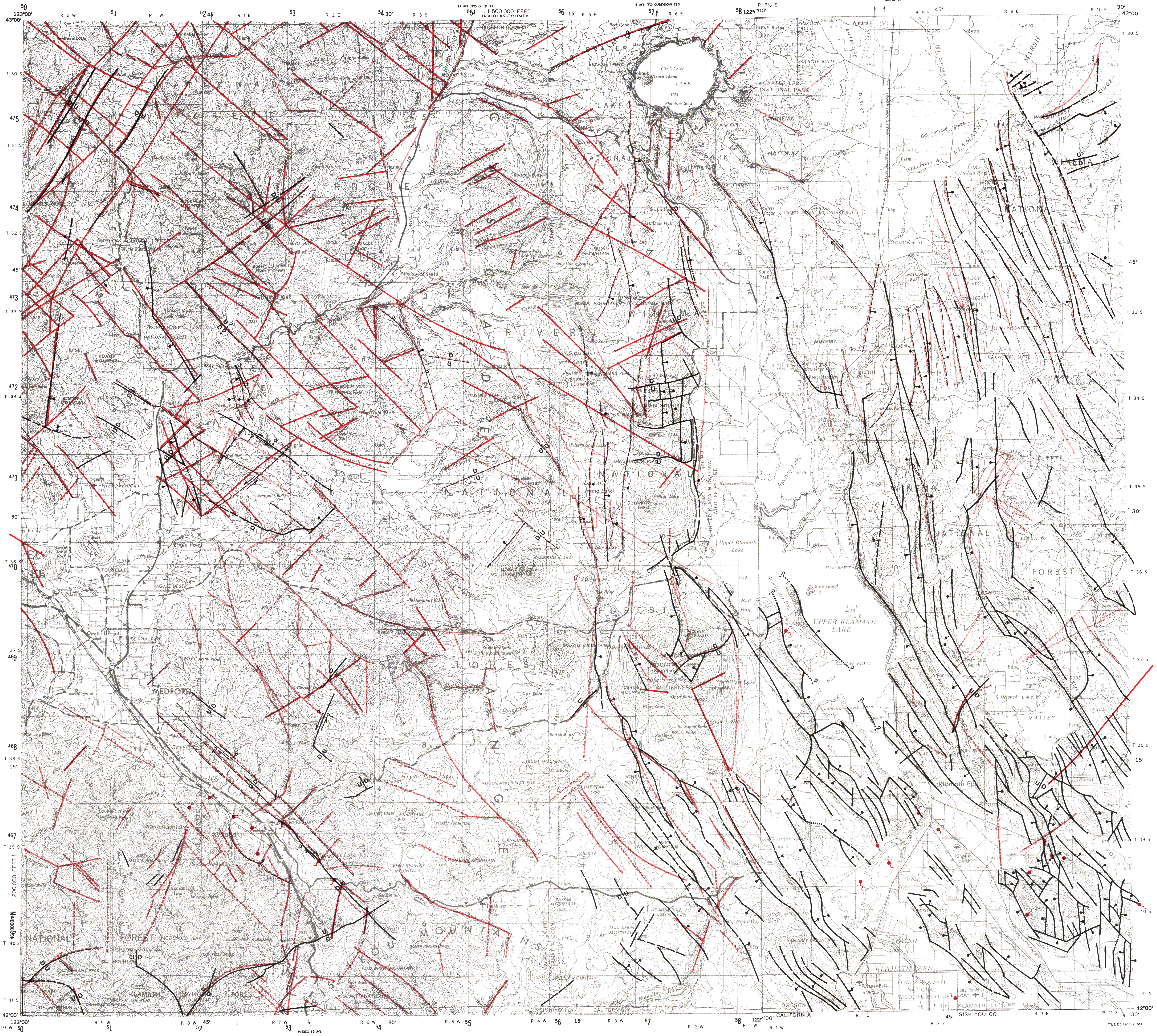
SpP 13

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

Fault and Lineament Map of the Eastern Part of Medford and Western Part of Klamath Falls – 1° x 2° AMS Quadrangles

1981

By C.A. Nelson, C.F. Kienle, R.D. Lawrence



Scale 1:250,000

5 0 5 10 15 20 Statute Miles

5 0 5 10 15 20 25 30 Kilometers

5 0 5 10 15 Nautical Miles

CONTOUR INTERVAL 200 FEET
WITH SUPPLEMENTARY CONTOURS AT 100 FOOT INTERVALS
TRANSVERSE MERCATOR PROJECTION

KNOWN FAULTS COMPILED FROM:

Hardyman, and others, 1972

Riccio, 1978.

Robison, 1972.

U.S. Army Corps of Engineers, 1980.

THERMAL SPRINGS DATA MODIFIED FROM:

Bowen and Peterson, 1970.

Bowen and others, 1978.

Riccio, 1978.

LINEAMENTS FROM:

- Topographic map (USGS - 1:62,500 or 1:24,000 scale)
- SLAR (Side Looking Airborn Radar - 1:250,000 scale)
- ERTS (Earth Resources Technology Satellite - 1:500,000 scale)
- U-2 flight imagery (1:125,000 scale)

GEOLOGIC SYMBOLS

- KNOWN FAULTS.
- FAULTS INFERRED FROM LINEAMENTS.

FAULTS: Solid where exposed, dashed where approximate, dotted where covered, queried where questionable.

- U and D denote sense of apparent vertical offset.
- Apparent dip slip; ball on downthrown side.
- Strike Slip; parallel arrows indicate sense of slip.
- Non-Thermal Springs with apparent structural control.
- Thermal Springs

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES