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MAP SHOWING ANALYSIS OF LINEAR FEATURES IN THE WALLACE, IDAHO-MONTANA 1° X 2° QUADRANGLE

By

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INTRODUCTION

Remote sensing studies in the Wallace, Idaho-Montana 1° x 2° quadrangle (fig. 1) concentrated on analysis of lineaments and arcuate-to-circular features identified in Landsat Multispectral Scanner (MSS) images. As used here, lineament refers to a "simple or composite linear feature of a surface whose parts are aligned in a rectilinear or slightly curvilinear relationship and which differ distinctly from the patterns of adjacent features and presumably reflect a subsurface phenomenon" (O'Leary and others, 1976, p. 1467). All of the lineaments described below are composite in that they consist of numerous linear streams, ridges, and escarpments. Most of the linear features comprising these lineaments are stream segments, but some consist of linear ridges and escarpments; tonal anomalies representing linear arrangements of bedrock exposures or vegetation are sparse. Lineaments are generally recognized by the presence of a higher areal density of linear features than is present in adjacent terrain; in some cases the contrast is enhanced by the presence of several long linear features. One area is characterized by the presence of many linear features of one general azimuthal direction, but it does not have the high length-to-width ratio that is typical for lineaments. Instead, this concentration is crudely elliptical. We refer to this more localized, but potentially important, feature as a "concentration of linear features" and discuss it separately.

Linear features were mapped on both small- and moderately large-scale MSS images. The close spatial arrangement and, hence, possibly genetic relationship of linear features comprising some lineaments is more readily recognized in small-scale images. Also, broad regional coverage, commonly at small scale, permits delineation of the most continuous lineaments, some of which may terminate or become discontinuous near the quadrangle margins. Better definition of lineaments commonly requires detailed analysis facilitated by using larger-scale images. The small-scale regional compilations were made using 1:2,500,000-scale MSS band 5 (0.6-0.7 micrometers) and 7 (0.8-1.1 micrometers) image mosaics prepared by the U.S. Soil Conservation Service. The larger-scale compilation of linear features was prepared for the Wallace quadrangle and the adjacent area using 1:350,000-scale digitally processed MSS band 5 and 7 images and a 1:250,000-scale digitally processed color-infrared composite image.

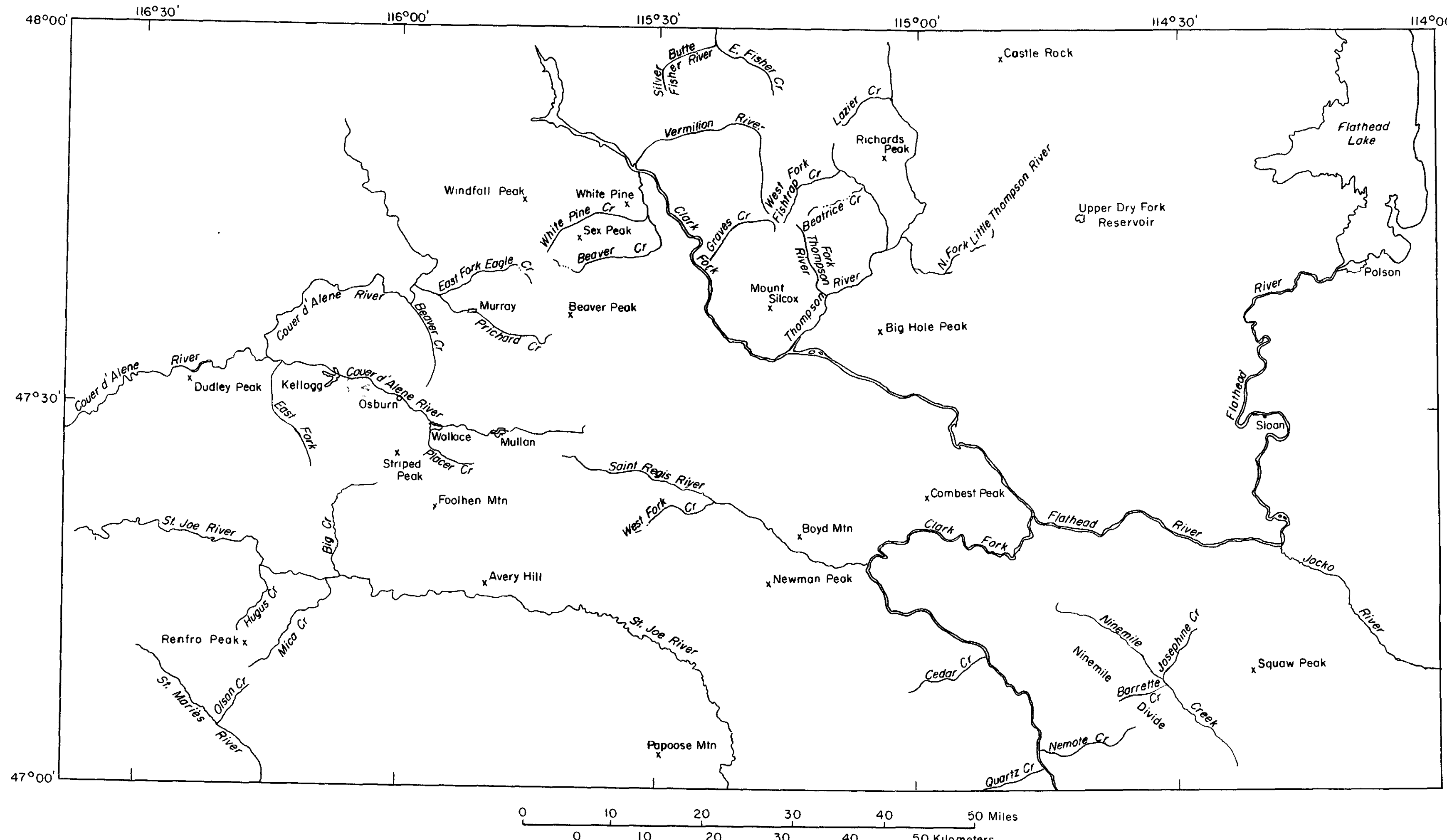
Most of the arcuate features consist of stream segments that connect to form arcuate to crudely circular or elliptical drainage patterns which are anomalous with respect to the adjacent terrain (figs. 1 and 2). In some cases, these features are composites of streams and ridges. Although these individual patterns vary considerably, in the interest of brevity we refer to them as a single broad category of arcuate features.

The main objective of this lineament analysis was to delineate previously unrecognized fractured areas that may be important for localizing certain metal deposits. Some of the mapped linear features in the MSS images clearly reflect the presence of major, steeply dipping, transcurrent faults (fig. 3), but many others are not readily ascribed to known structural features. Similarly, while many of the arcuate-to-circular features appear to be morphological expressions of intrusive bodies, others are of unknown origin. This study focuses on the unexplained lineaments, concentrations of linear features, and arcuate features. Because of substantial differences in the analytical approach used and in the results obtained, the regional analyses and the more local quadrangle analyses of lineaments and arcuate features are described separately.

In order to determine the geologic significance of these lineaments, concentrations of linear features, and arcuate features, we compared their locations, dimensions, and orientations with the principal tectonic elements (fig. 3), features seen in a simple Bouguer gravity map of part of the western Cordillera (fig. 4), and the aeromagnetic and complete Bouguer gravity maps of the quadrangle (fig. 5 and fig. 6a, respectively).

REGIONAL ANALYSIS OF LINEAMENTS

The central part of the region for which linear features were mapped at the 1:2,500,000 scale (fig. 1) is marked by the presence of a series of west- to west-northwest-trending, linear and slightly curvilinear features. These features correspond to the Osburn-Ninemile right-lateral strike-slip fault zone (fig. 3). This profound fault zone, which is approximately 20-25 km wide where it transects the Wallace quadrangle, is also characterized by the presence of a high areal density of relatively short, northeast- to north-trending linear features (fig. 1). Although these features do not correspond to mapped faults, the



Index map showing locations of topographic and cultural features referred to in the text

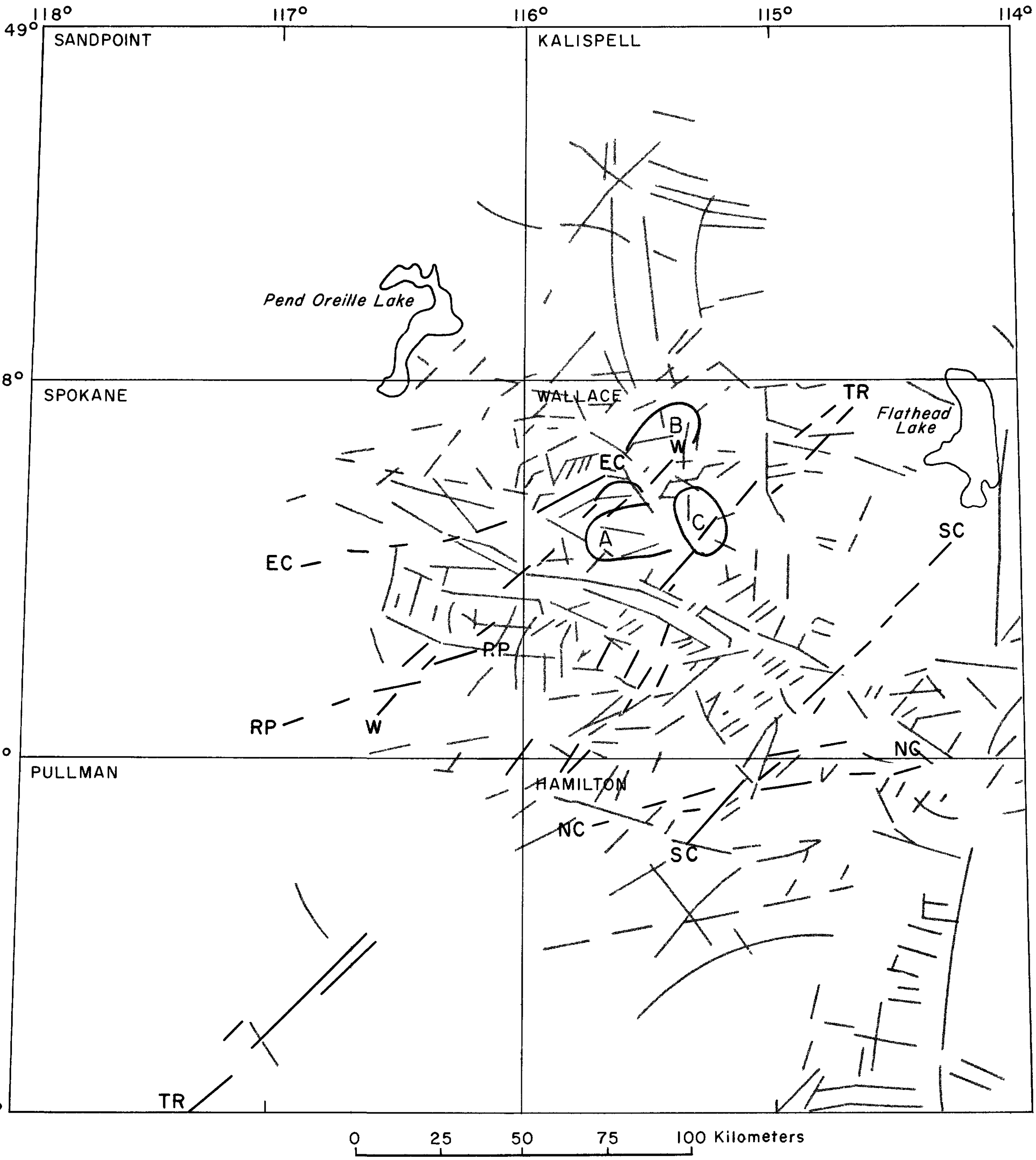


Figure 1.--Linear features and arcuate features in western Montana, northern Idaho, and eastern Washington compiled on Landsat MSS band 5 and 7 image mosaics and shown on the Wallace, Id.-Mont. 1° x 2° quadrangle and selected adjacent 1° x 2° quadrangles. Explanation of symbols used on map: W- Wallace lineament; TR- Thompson River lineament; SC- Sloan-Cedar Creek lineament; EC- East Fork of Eagle Creek lineament; RP- Renfro Peak lineament; NC- Nemote Creek lineament. A, B, and C designate arcuate features discussed in the text.

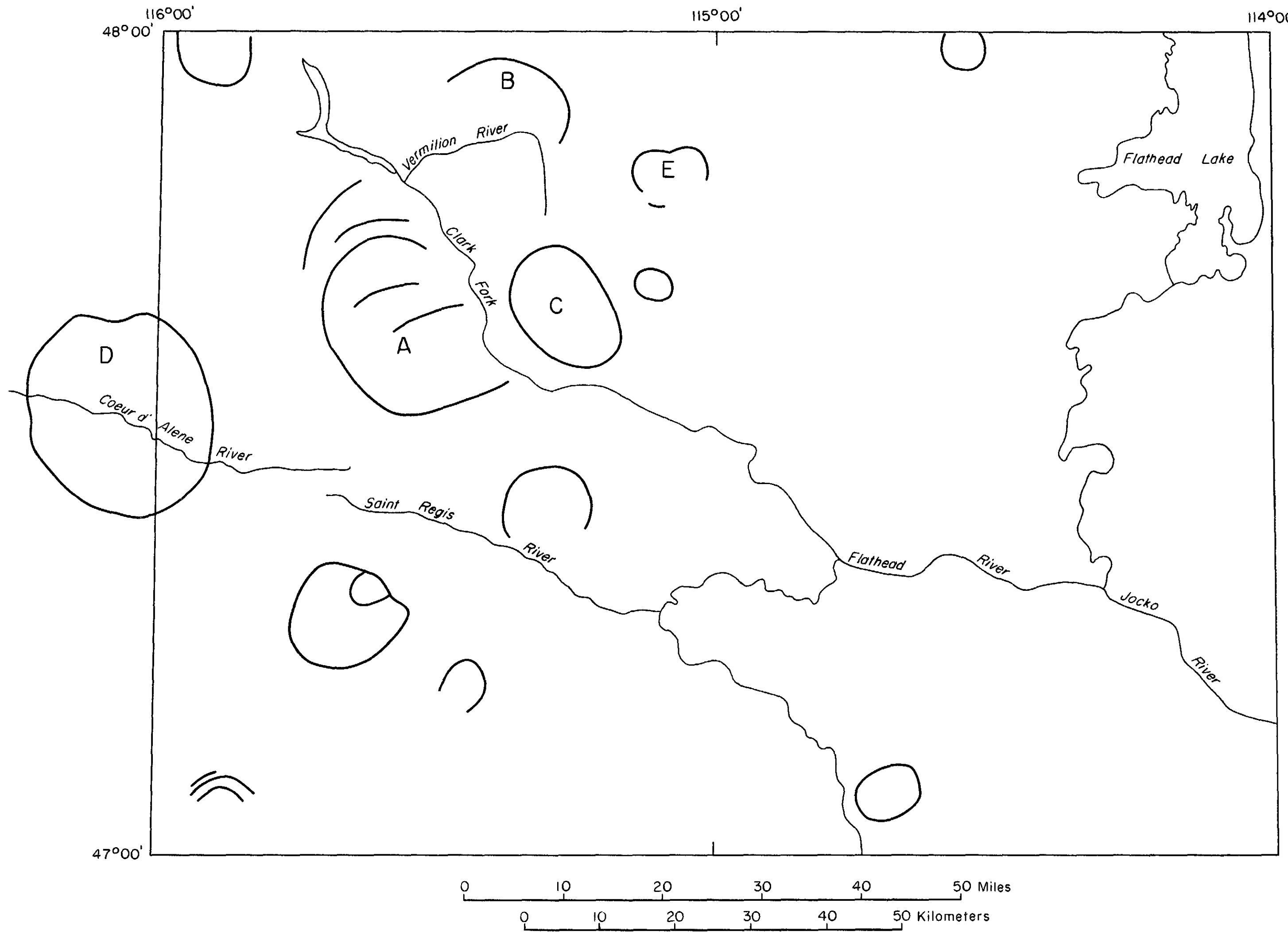


Figure 2.--Location of arcuate features in the Wallace, Id.-Mont. 1° x 2° quadrangle. Letters designate features discussed in the text.

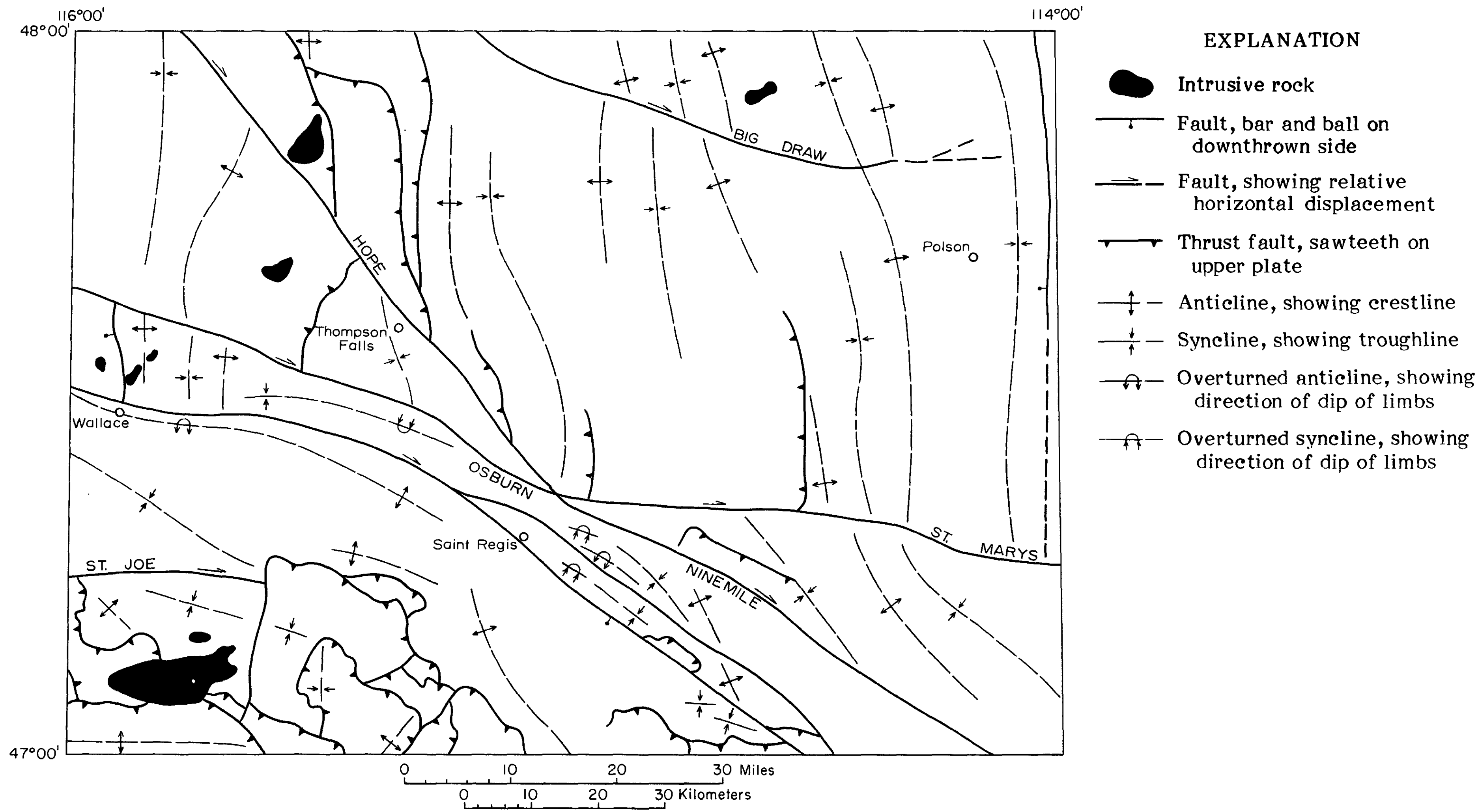


Figure 3.--Generalized structure map of the Wallace, Id.-Mont. 1^{o} x 2^{o} quadrangle (Harrison and others, 1981).

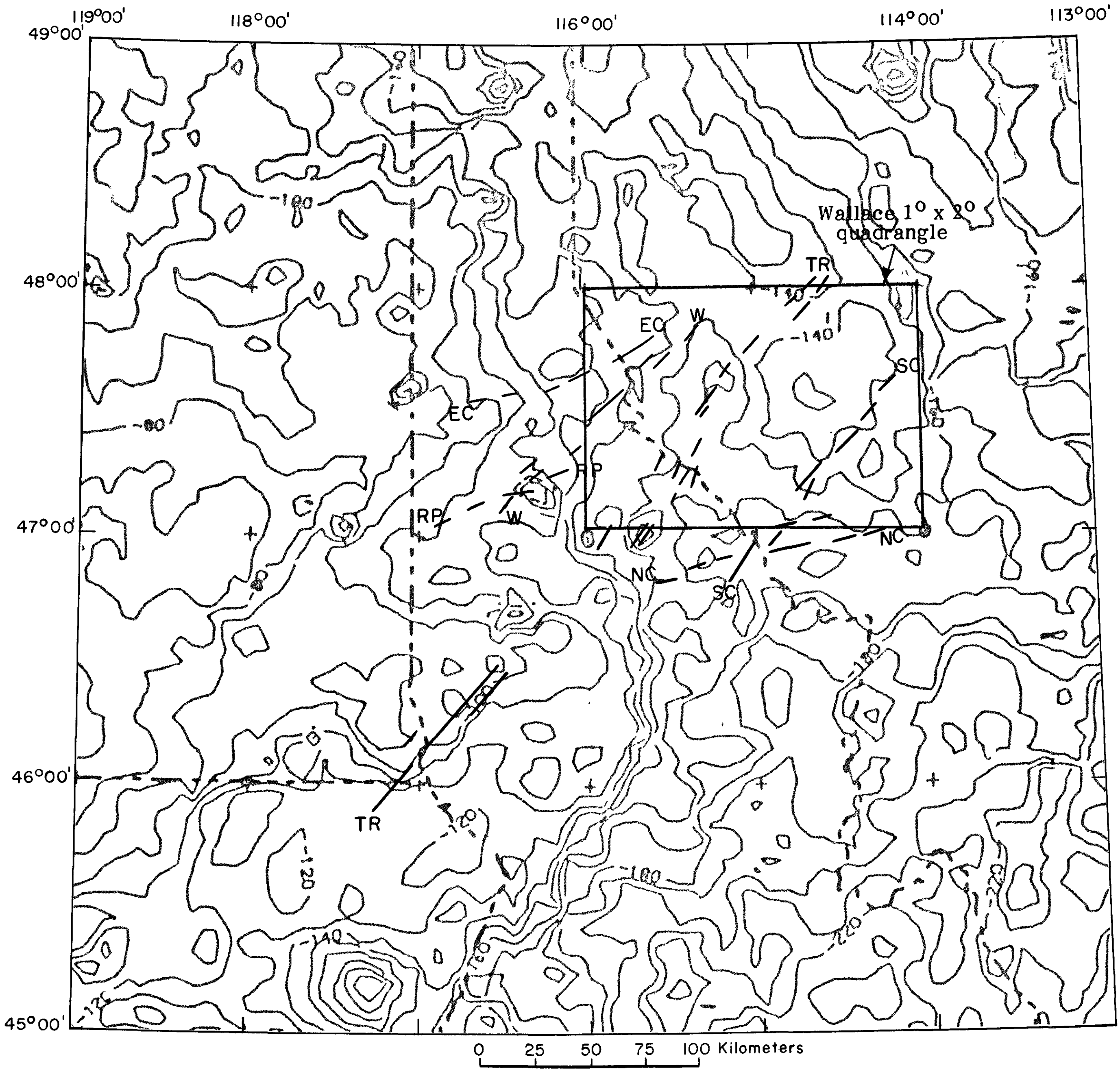


Figure 4.--Simple Bouguer gravity map of part of the northwestern United States (modified from Eaton and others, 1978) with regionally extensive linear features from figure 1. Contour interval 10 milligals.

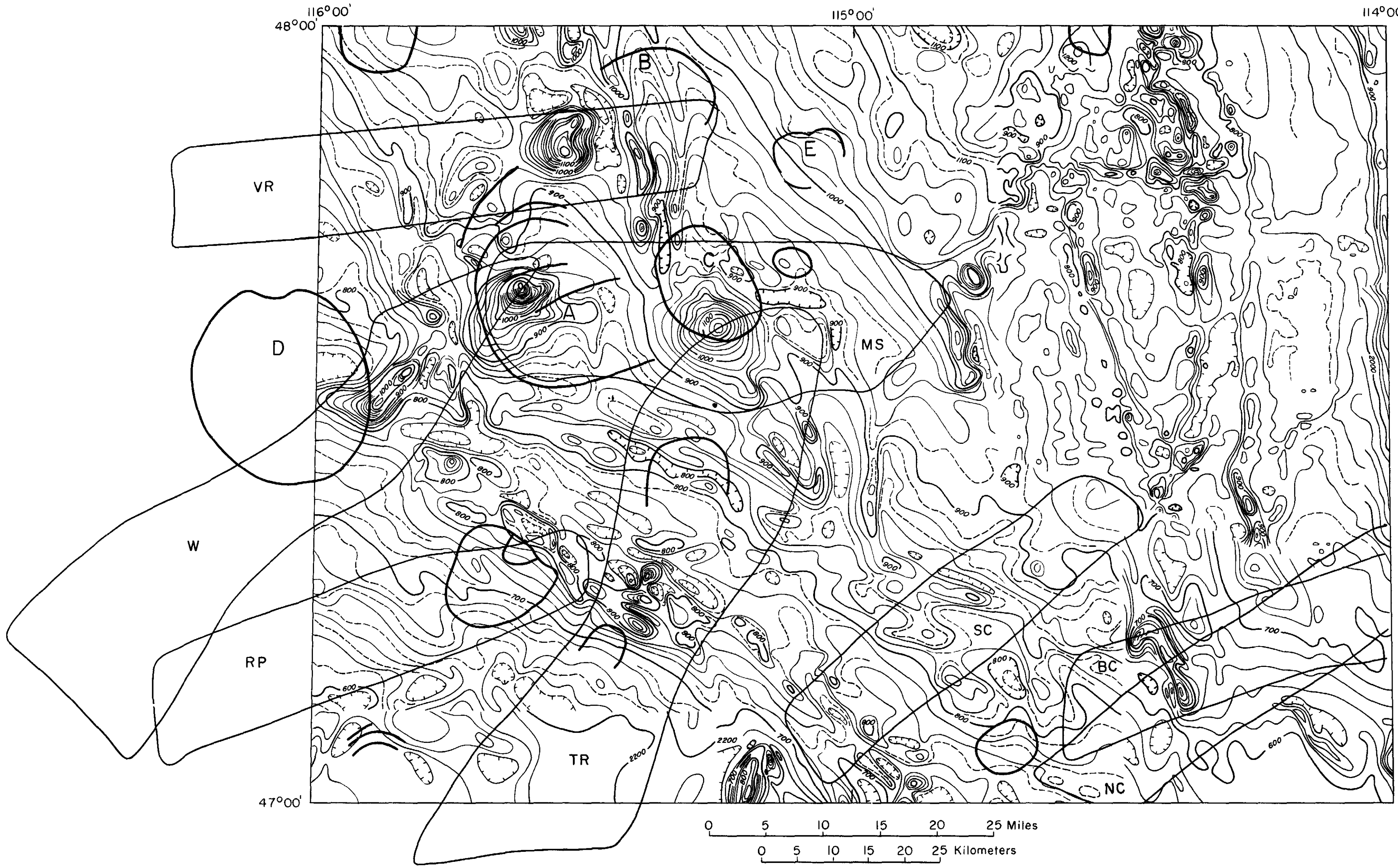


Figure 5.--Total intensity aeromagnetic map of the Wallace, Id.-Mont. 1° x 2° quadrangle (Kleinkopf and others, in press). Explanation of symbols used on map: W- Wallace lineament; TR- Thompson River lineament; SC- Sloan-Cedar Creek lineament; RP- Renfro Peak lineament; NC- Nemote Creek lineament; BC- Barrette Creek lineament; VR- Vermilion River lineament; MS- Mount Silcox concentration of linear features; A, B, C, D, and E correspond to arcuate features discussed in the text.

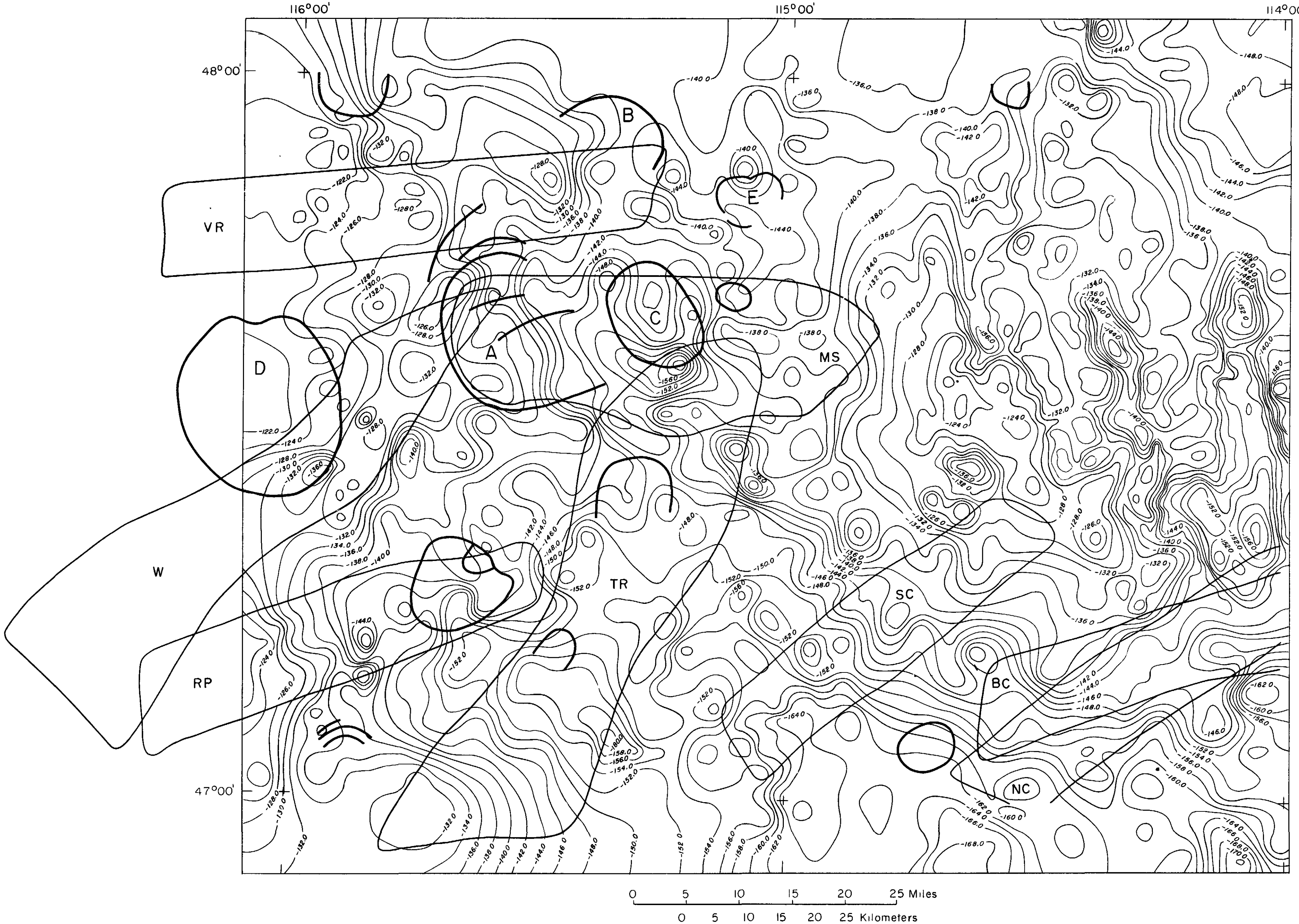


Figure 6a.--Complete Bouguer gravity map of the Wallace, Id.-Mont. 1° x 2° quadrangle (Kleinkopf and others, in press). Explanation of symbols used on map: W-Wallace lineament; TR- Thompson River lineament; SC-Sloan-Cedar Creek lineament; RP- Renfro Peak lineament; NC-Nemote Creek lineament; VR- Vermilion River lineament; BC-Barrette Creek lineament; MS- Mount Silcox concentration of linear features A, B, C, D, and E correspond to arcuate features discussed in the text.

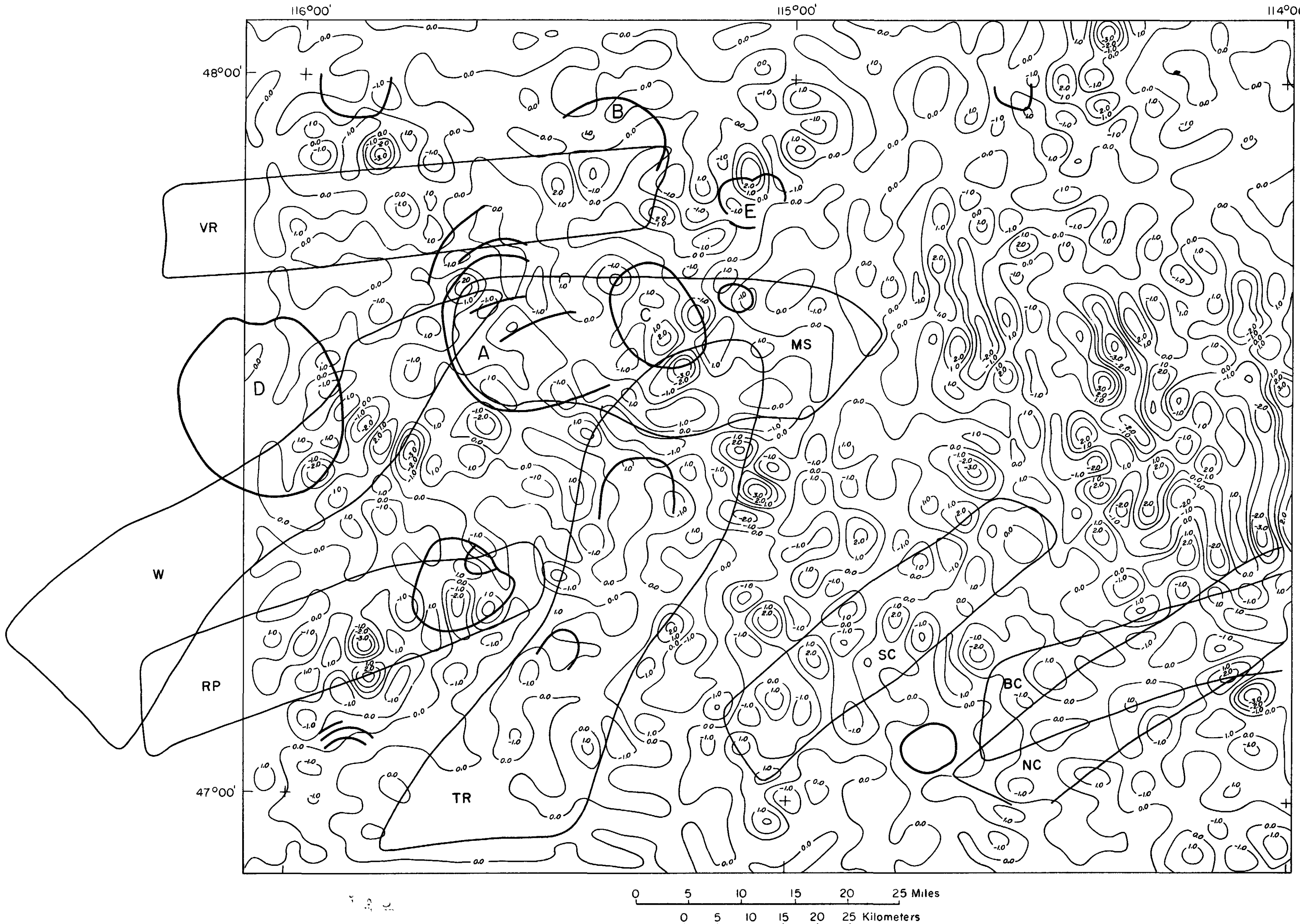


Figure 6b.--Second vertical derivative of complete Bouguer gravity map of the Wallace, Id.-Mont. $1^{o} \times 2^{o}$ quadrangle (Kleinkopf and others, in press). Explanation of symbols used on map: W- Wallace lineament; TR- Thompson River lineament; SC- Sloan-Cedar Creek lineament; RP- Renfro Peak lineament; NC- Nemote Creek lineament, VR- Vermilion River lineament; BC- Barrette Creek lineament; MS- Mount Silcox concentration of linear features A, B, C, D, and E correspond to arcuate features discussed in the text.

orientation of these linear features appears to change gradually in concert with the variation of the trace of the Osburn-Ninemile zone.

Other major mapped faults that are represented by linear features in figure 1 include the right-lateral, strike-slip Big Draw, Hope, and Saint Joe faults, and normal faults along the eastern margin of Flathead Lake near Polson (fig. 3). The Saint Mary's fault in the southeastern part of the quadrangle (fig. 3) is only locally represented by a single linear feature. The major thrust faults shown on figure 3 are poorly represented in the regional map of linear features because they generally have a subtle topographic expression not seen in the images. There is also little correlation between the linear features and the locations of fold axes (figs. 1 and 3).

Six major northeast-trending lineaments defined by linear features were identified on the 1:2,500,000-scale Landsat mosaics (fig. 1). Not all of the long linear features that trend northeast or east-northeast correspond to mapped faults. The longest of these features extends from northeasternmost Oregon to the northeastern margin of the Wallace quadrangle. We refer to this feature as the Thompson River lineament (TR, fig. 1) because many of the linear features along it represent linear segments within this drainage. The linear features comprising the Thompson River lineament within the Pullman, Wash. 1^{o} x 2^{o} quadrangle and southwestward into Oregon (fig. 1) are generally coincident with northeast-oriented faults located near the southern border of the Wallace quadrangle, but elsewhere there is little correspondence between mapped faults and these linear features. However, this regionally extensive lineament parallels a regional gradient present in the simple Bouguer gravity map (TR, fig. 4).

Linear features comprising the northeast-trending Wallace lineament (W, fig. 1) extend from the southeastern part of the Spokane, Washington 1^{o} x 2^{o} quadrangle to the northwestern part of the Wallace quadrangle. Mapped faults in this area trend dominantly west to west-northwest, northwest, and north. They typically have right-lateral displacement on the northwesterly oriented faults and normal displacement on the north-trending faults (Gott and Billings, 1967; Griggs, 1973; Harrison and others, 1974; Harrison and others, 1981). However, gem stocks north of Wallace and Mullan, Idaho, which lie along the Wallace lineament, are distinctly northeast-elongate. In addition, a northeast-oriented normal fault mapped in the southeastern part of the Spokane quadrangle (Griggs, 1973) is represented by a distinctive linear feature in the image mosaics. Nevertheless, mapped northeast-trending faults are relatively uncommon along the Wallace lineament. Yet, this lineament, which is discussed in more detail later, is coincident with prominent gravity features throughout its length (W, fig. 4 and 6a), and is expressed in the aeromagnetic map pattern by the northeast elongation of intrusives in the gem stock area (W, fig. 5).

Other prominent northeast-trending linear features constitute the Sloan-Cedar Creek lineament (SC, fig. 1) that transects the eastern part of the Wallace quadrangle and extends southwestward into the northern part of the Hamilton, Montana-Idaho 1^{o} x 2^{o} quadrangle. Other than a fault scarp that trends southwestward from Sloan, Mont. (Harrison and others, 1981), none of the other linear features in this lineament correspond to mapped faults. The Sloan-Cedar Creek lineament is not as well expressed in the simple Bouguer gravity map within the Wallace quadrangle as are the Wallace and Thompson River lineaments, but the southwestern projection of this lineament is nearly on line with the trend of a very steep gravity gradient.

One of the most conspicuous alignments of linear features delineated in the Landsat MSS mosaics forms the east-northeast-trending Eagle Creek lineament (EC, fig. 1). This lineament extends from Dudley Peak in the Spokane quadrangle northeastward along the East Fork Eagle Creek to White Pine Creek in Montana. Although northeast-trending faults are prominent components of the structural framework south and southwest of Dudley Peak (Griggs, 1973), only one small fault of this trend has been mapped along the part of the lineament in the Wallace quadrangle (Harrison and others, 1981).

The Renfro Peak lineament (RP), as defined on figure 1, is entirely within the Spokane, Washington 1^{o} x 2^{o} quadrangle and appears to terminate at the St. Joe River. Faults mapped in this part of the Spokane quadrangle trend mainly northwest and north (Griggs, 1973), and none correspond to the component linear stream segments and ridges. Although anomalies in the regional simple Bouguer gravity map (fig. 4) are dominantly northeast-trending and closely correspond to the trends of the Wallace and Thompson River lineaments, a subtle east-northeast trend is suggested in the vicinity of the Renfro Peak lineament by inflections in the gravity contours (RP, fig. 4).

Another east-northeast-trending lineament identified in the 1:2,500,000-scale MSS image mosaics transects the southeastern corner of the Wallace quadrangle and is referred to as the Nemote Creek lineament (NC, fig. 1). As with the other regional lineaments, faults that might correspond to the lineament are generally lacking. However, as the more detailed quadrangle analysis will show, the presence of this lineament is supported by the statistical analysis of linear features and patterns seen in the gravity map.

ARCUATE FEATURES

Three arcuate features were mapped on the MSS band 7 1:2,500,000-scale image mosaic (fig. 1); none were identified in the band 5 mosaic. All three arcuate features are in the Wallace quadrangle and situated around intrusive bodies, two of which are partially exposed (A and B, fig. 1) and one that is buried (C, fig. 1). The locations, topographic configurations, and geophysical characteristics are discussed in detail in a subsequent section.

In summary, three northeast- and three east-northeast-trending lineaments not related to known structures were identified in the Landsat MSS band 5 and band 7 image mosaics, along with other lineaments that reflect the presence of major transcurrent faults. Thrust faults and folds are not evident in these mosaics. In general, these six lineaments do not correspond to faults mapped in the quadrangle, but they appear to be expressed in the regional Bouguer gravity map by orientation of anomalies, trends of regional gradient, or inflections of contour lines. We tentatively view these six lineaments as being possible indicators of regional fracture zones that probably have little or no offset. Evaluation of this hypothesis is conducted through an integrated analysis of a detailed map of linear features and the geologic, gravity, and aeromagnetic maps compiled at the quadrangle scale.

QUADRANGLE ANALYSIS OF LINEAMENTS

A detailed analysis of lineaments within and along the borders of the Wallace quadrangle was conducted using Landsat MSS scene E-2231-17504 acquired on September 10, 1975. Computer compatible tapes were processed applying a three-point linear stretch to improve the image contrast (Krohn, 1979). Negative films were then generated on a digital film recorder and prints were made at a scale of approximately 1:350,000. Linear features were mapped on these prints and subsequently on a 1:250,000-scale color-infrared composite image that incorporated MSS bands 4 (0.5-0.6 micrometers), 5 (0.6-0.7 micrometers), and 7 (0.8-1.1 micrometers). Finally, the linear features were digitized for statistical analysis and plotting. For the purpose of digitizing, curvilinear features were divided into individual linear segments; obvious linear and curvilinear cultural features were excluded by reference to topographic maps.

Although most of the major mapped, steeply dipping faults are represented by aligned linear features delineated in the larger scale images (fig. 3), the pattern is too complex to permit detailed visual analysis. Therefore, a statistical analysis was employed to identify the significant trends that might be present in the population of linear features (see Appendix for detailed discussion). Linear features belonging to significant trends were plotted and contoured in order to facilitate recognition of lineaments. The results of the initial phase of the analysis, in which rigorous statistical guidelines were used, indicated the presence of several lineaments in the quadrangle, but the boundaries of some were difficult to define. In order to improve the definition of these and other suggested lineaments, the guidelines were relaxed somewhat to permit evaluation of maxima located within the significant trends derived in the initial phase of analysis.

The boundaries of lineaments within the quadrangle were estimated using contour maps that show areal concentration of linear features of selected trends. Note that the number of linear features mapped in the larger-scale MSS images is considerably higher outside of as well as within the lineaments than was mapped on the smaller-scale mosaics (fig. 1).

The frequency distribution of linear features for 1-degree class intervals of azimuthal direction (fig. 7) is characterized by a broad minimum centered near N30°W and a very broad maximum that encompasses the remaining azimuthal range. Four statistically significant azimuthal trends were identified in the broad maximum and used as a basis for the initial quadrangle analysis of the linear feature data (see Appendix for discussion).

Seven lineaments and one anomalous concentration of linear features were defined during the quadrangle analysis. The lineaments were divided into those trending N40°-60°E, N19°-33°E, and N71°-80°E. The concentration of linear features trends N89°E and N82°-88°W.

N40°-60°E-TRENDING LINEAMENTS

The Nemote Creek, Wallace, and Sloan-Cedar Creek lineaments were identified on the plot and contour map of the N40°-60°E-trending linear features (NC, W, and SC, fig. 8).

Nemote Creek Lineament

The Nemote Creek lineament is a northeast-trending feature located in the southeastern corner of the quadrangle. It generally corresponds to the Nemote Creek lineament identified in the regional analysis (NC, fig. 1). The Nemote Creek lineament transects the lithologic layering and fold axes at high angles (Harrison and others, 1981). There are a few faults trending N40°-60E° in this vicinity, but the majority of them are northwest-oriented and are associated with the Osburn-Ninemile fault zone.

The strongest evidence that this lineament is a surface expression of a crustal discontinuity are features present in the complete Bouguer gravity map and the second vertical derivative map computed from the Bouguer gravity data (figs. 6a and 6b, respectively). The east-central part of the complete Bouguer gravity map is dominated by a broad, generally north-northwest-oriented positive anomaly. This anomaly is related to the Purcell geanticline, which brought the rocks of the Prichard Formation and possibly crystalline basement closer to the surface than in adjacent regions. The anomaly is disrupted or terminated to the southeast where the Nemote Creek lineament transects the quadrangle (fig. 6a). In the second vertical derivative map, which is designed to isolate anomalies and subdue minor features, the entire southeastern part of the quadrangle has fewer anomalies than the adjacent regions to the north and northwest (fig. 6b). The Nemote Creek lineament is located just southeast of this boundary and parallel to it. The possible significance of this relationship is discussed in a later section.

Wallace Lineament

The Wallace lineament, defined by the N40°-60°E-trending linear features, is located at the western margin of the quadrangle (W, fig. 8). This feature is coincident with the Wallace lineament identified in the 1:2,500,000-scale mosaics (W, fig. 1).

As previously mentioned, alignment of anomalies in both the gravity and aeromagnetic maps give some indication of a structural feature in this area. In the complete Bouguer gravity map (W, fig. 6a) this general area is a steep southeast-dipping gradient separating a region of high gravity in the northwest from low gravity to the southeast. The Wallace lineament is situated roughly 3 to 12 km northwest of the steepest part of this gradient and is coincident with four anomalies that are, to varying degrees, elongate in the northeast direction.

Although the northeast-trending aeromagnetic anomaly that reflects the elongation of the gem stocks (W. fig. 5) is also coincident with the Wallace lineament, this trend is not evident in the total intensity map elsewhere along the lineament.

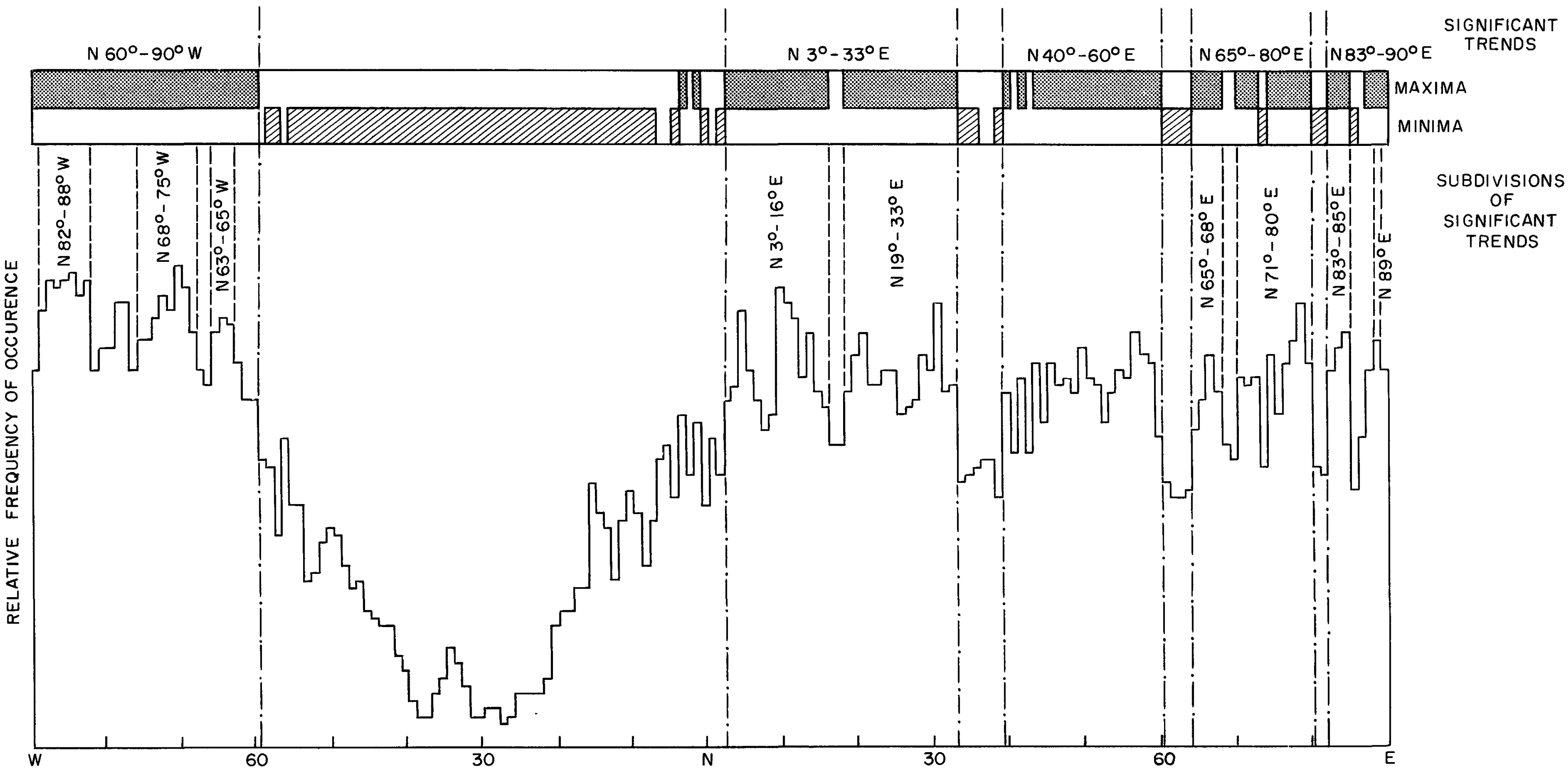


Figure 7.--Length-weighted strike-frequency plot or linear features. Significant maxima and minima from strike frequency analysis, interpreted significant trends, and subdivision of significant trends are shown.

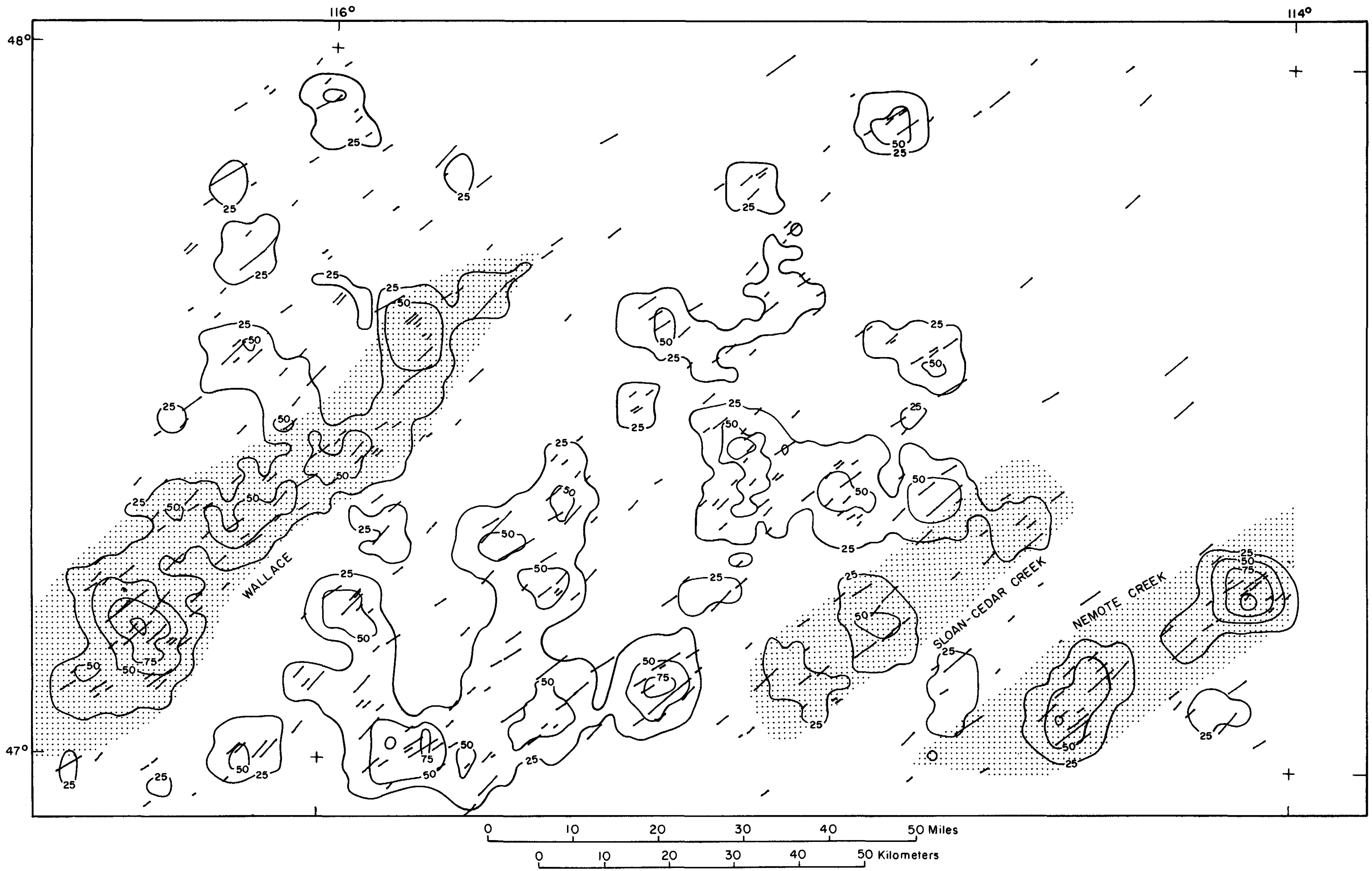


Figure 8.--Linear features map and contour map of N40°-60°E-trending linear features in the Wallace, Id.-Mont. $1^{\circ} \times 2^{\circ}$ quadrangle. Stipple patterns locate approximate boundaries of the Nemote Creek lineament, the Wallace lineament, and the Sloan-Cedar Creek lineament.

Sloan-Cedar Creek Lineament

Although less well-defined, the Sloan-Cedar Creek lineament is indicated in the map of N40°-60°E-trending linear features northwest of the Nemote Creek lineament (fig. 8). The Nemote Creek lineament intersects the Sloan-Cedar Creek lineament (SC, fig. 1). Most of the linear features located within the Sloan-Cedar Creek lineament are moderately long, and many mark inflections in the contours in the aeromagnetic and gravity maps (SC, figs. 5 and 6a, respectively). The second vertical derivitive map (fig. 6b) shows this lineament situated very close to the boundary between the region in the north with numerous anomalies and the area of few anomalies to the southeast.

N19°-33°E-TRENDING LINEAMENTS

Thompson River Lineament

A northeast-oriented belt of closely spaced N19°-33°E-trending linear features defines the Thompson River lineament (TR, fig. 9), which corresponds to the Thompson River lineament identified on the 1:2,500,000-scale image mosaic. The northwest-striking gravity gradient in the central and southeastern part of the quadrangle is locally disrupted in the vicinity of the Thompson River lineament, especially in the south-central part of the quadrangle (TR, fig. 6a). In the second vertical derivative gravity map (fig. 6b), a linear zone with notably few isolated anomalies corresponds in width and orientation to the Thompson River lineament. Here, as in the southeastern part of the quadrangle, the lineament and the coincident gravity zone cross highly diverse lithologic units at high angles. This lineament is only interrupted where it crosses a buried intrusive beneath Mount Silcox. In contrast, the northwest-trending aeromagnetic anomalies are interruted only locally along this lineament (TR, fig. 5).

N71°-80°E-TRENDING LINEAMENTS

Linear features that trend N71°-80°E are generally uniformly distributed in the quadrangle, except in the broad basin around Flathead Lake where these, as well as the features of other orientations, are relatively sparse (fig. 10). However, in a few areas, the linear features are considerably longer than in the adjacent terrain and are moderately closely spaced. One such area is located in the southwestern part of the quadrangle (fig. 10) where several long, as well as short, linear features are aligned. These features are coincident in part with the regional Renfro Peak lineament (RP, fig. 1) but extend further into the quadrangle than is indicated by this small-scale map.

Renfro Peak Lineament

The long linear features at the western margin of the quadrangle are nearly coincident with sharp inflections in the gravity contour lines (RP, fig. 6a, RP, fig. 10). The lineament is indicated in the second vertical derivative gravity map (fig. 6b) by a east-northeast-oriented zone of very narrow anomalies. Evidence in the aeromagnetic map is less well defined, but inflections on the generally west-northwest trending anomalies (RP, fig. 5) may be related to the presence of this lineament. However, the inflections may be attributed to the distribution of magnetically contrasting lithologic units (Harrison and others, 1981). Further to the east in the Osburn-Ninemile fault zone, east-northeast-trending aeromagnetic anomalies are present in the general area of the linear features along this trend. However, the correspondence between these linear features and the locations of the aeromagnetic anomalies is too general to be definitive, and east-northeast trends are not prominent in the gravity maps in this part of the quadrangle (figs. 6a and 6b). We therefore restrict the extent of the Renfro Peak lineament within the quadrangle to the approximately 43-kilometer length shown in fig. 10. This length, combined with its extent in the Spokane, Wash. quadrangle (RP, fig. 1), results in a total length of approximately 100 km.

Vermilion River Lineament

Several long N71°-80°E-trending linear features in the northwestern part of the quadrangle, which are mainly stream segments, constitute a lineament that is approximately 12 km wide. As with the other lineaments, few faults of this trend are present along this lineament, which we refer to as the Vermilion River lineament (VR, fig. 10), and the linear features cannot be attributed to the trend of bedding (Harrison and others, 1981). In the second vertical derivative gravity map (fig. 6b), the lineament is generally coincident with a zone of fewer and broader anomalies than are present in the areas to the north and south. Near the western margin, the anomalies within the lineament are northeast-elongated. There is little expression of this trend in the aeromagnetic map (VR, fig. 5), except that the northern border of the aeromagnetic anomaly related to the intrusive exposed along the Vermilion River (fig. 3) is northeast-trending. The other northeast-oriented aeromagnetic anomalies located along this lineament can be accounted for by the trends of the lithologic units (Harrison and others, 1981, fig. 5).

Barrette Creek Lineament

The Barrette Creek lineament is defined on the map of N71°-80°E-trending linear features (BC, fig. 10) by an alignment of moderately closely spaced linear features in the southeastern part of the quadrangle. This lineament overlaps the Nemote Creek lineament (fig. 9), and most of the gaps in the areal distribution of Barrette Creek features tend to be filled in by linear features making up the Nemote Creek lineament. Together, these lineaments mainly refect the two dominant trends of secondary streams in this part of the quadrangle. The gravity features mentioned during the discussion of the Nemote Creek lineament also apply to the Barrette Creek lineament (BC, figs. 6a and 6b). Although the Barrette Creek features are somewhat more scattered than those along the Nemote Creek lineament, both the northwest and southeast borders are well defined by virtue of the paucity of linear features in the adjacent areas.

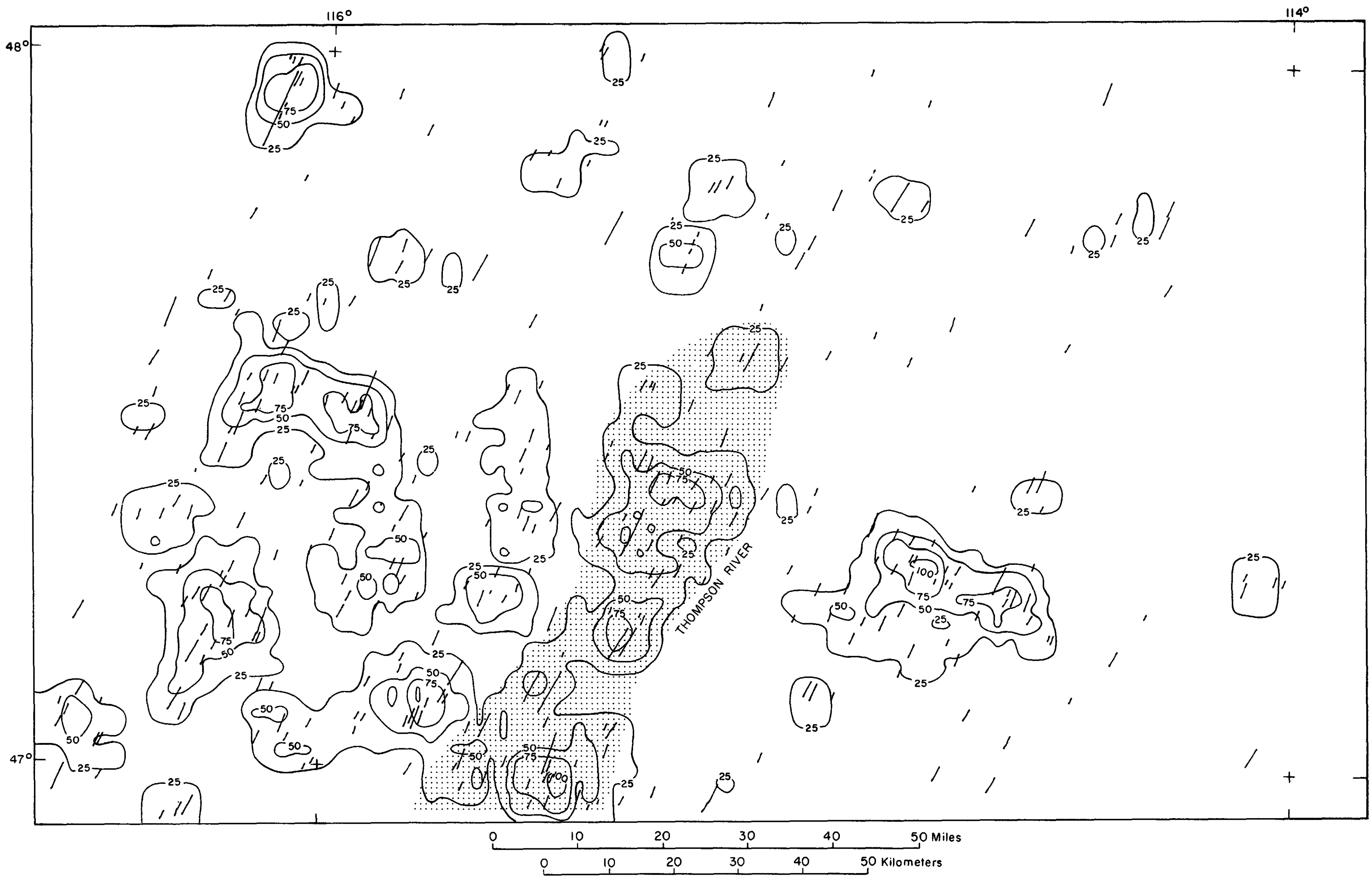


Figure 9.--Linear features map and contour map of the N19°-33°E-trending linear features. The stipple pattern locates the Thompson River lineament.

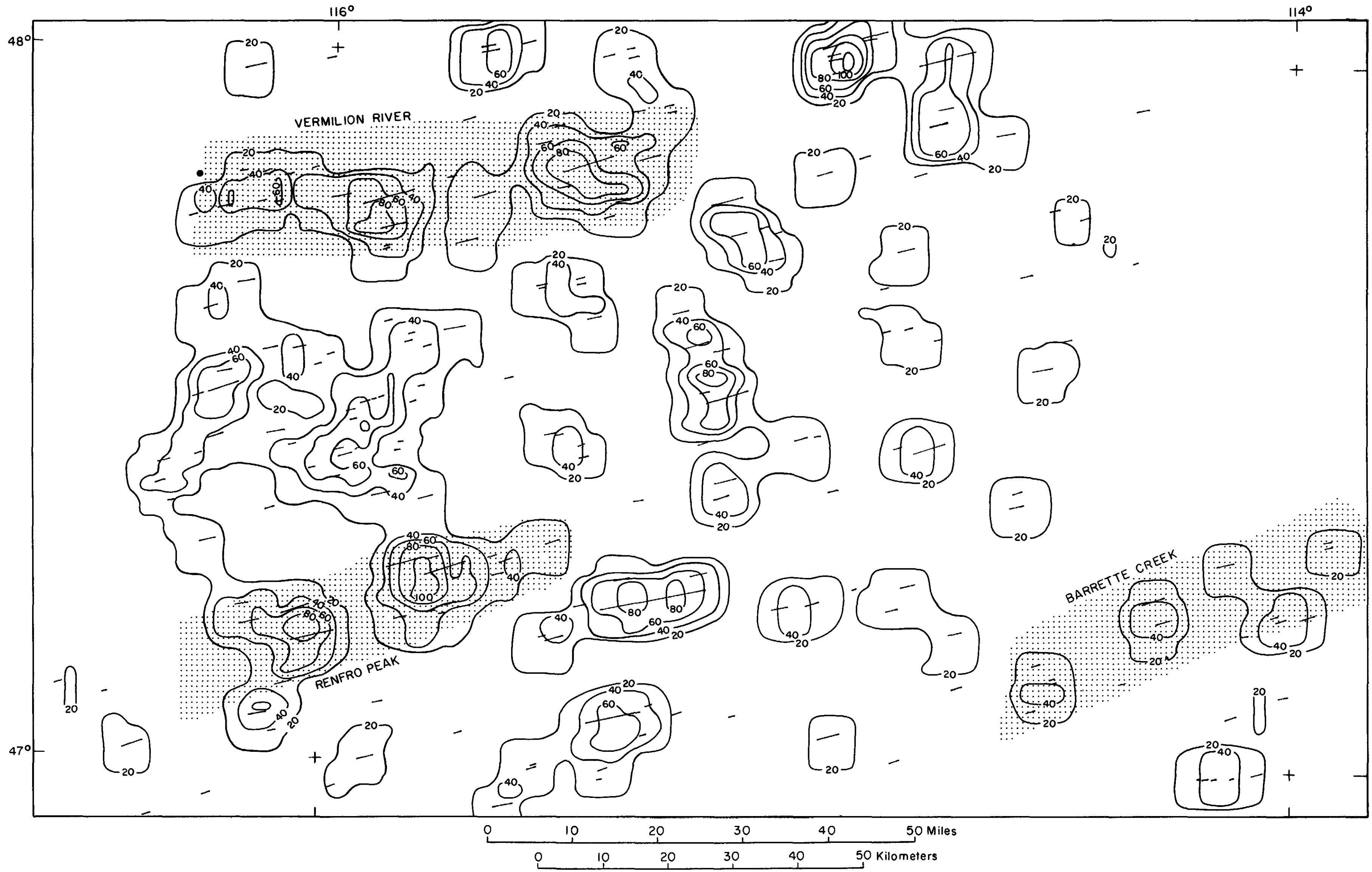


Figure 10.--Linear features map and contour map of N71°-80°E-trending linear features in the Wallace, Id.-Mont. 1° x 2° quadrangle. The stipple pattern locates the Renfro Peak lineament, the Barrette Creek lineament, and the Vermilion River lineament.

N89°E- and N82°-88°W-TRENDING LINEAR FEATURES

Mount Silcox Concentration of Linear Features

This concentration of linear features outlined near the center of the map of N89°E- and N82°-88°W-trending linear features (MS, fig. 11) is not related to any mapped faults, and the feature is nearly normal to the general trend of lithologic layering. The prominent gravity low located near the south-central part of the concentration (MS, fig. 6b) is related to a buried intrusive (Kleinkopf and others, in press). Although this gravity anomaly is circular, many of the other anomalies elsewhere in the area of the concentration are distinctly elongate in a west to west-northwest direction. A similar pattern is present in this area on the aeromagnetic map (MS, fig. 5). We refer to this concentration of linear features as the Mount Silcox concentration. The narrow gap between the eastern and western parts of the concentration indicated by the contour lines is related to the location of the Clark Fork Valley (fig. 7). The concentration of similarly trending linear features located in the west-central part of the quadrangle is related to the west-oriented strike-slip faults in the Osburn-Ninemile fault zone (figs. 3 and 11).

Relationships among the Mount Silcox concentration and the gravity and aeromagnetic map patterns are particularly interesting at the western terminus of the concentration (MS, fig. 11). The concentration terminates at the exposed part of the 100-million-year-old intrusive body located southwest of White Pine, Mont. (figs. 3 and 11). The aeromagnetic anomaly is generally northeast-trending, but a prominent westward trend is present where the concentration of linear features terminates (MS, figs. 11 and 5). In addition, the northern part of this aeromagnetic anomaly is west trending. Although the gravity anomaly (fig. 6a) is displaced northwestward with respect to the aeromagnetic anomaly (fig. 5), it also has a west-oriented northern boundary, and west trends are evident along the eastern side. The Wallace lineament and the northeast-trending alignment of gravity anomalies that mark this lineament terminate where they intersect the Mount Silcox concentration.

One lineament mapped in the 1:2,500,000-scale image mosaics, the East Fork Eagle Creek (EC, fig. 1), was not confirmed in the quadrangle analysis of linear features. Although there appears to be a concentration of N65°-80°E-trending linear features in the general area of the lineament (fig. 12), the density of features does not appear to be very different from that of several other areas on this map. Therefore, we do not include this feature in the list of lineaments recognized within the quadrangle.

QUADRANGLE ANALYSIS OF ARCUATE FEATURES

Interpretation of the MSS images in the quadrangle resulted in identification of 13 arcuate features (fig. 2). Of these, three correspond to the arcuate features mapped on the 1:2,500,000-scale image mosaic (A, B, and C, figs. 1 and 2). The arcuate streams and ridges around the intrusive body near Sex Peak (A, fig. 2) are especially distinctive on both sets of images. The aeromagnetic total intensity high that is caused by this intrusive and the arcuate features agree reasonably well, except in the northern part where several incised arcuate streams are present well beyond the aeromagnetic anomaly (A, fig. 5). As mentioned previously, the gravity map pattern is complex in this area (A, fig. 6a). The gravity high is displaced to the northwest with respect to the aeromagnetic anomalies and the exposed part of the intrusive. These spatial differences may be related to compositional differences either within the unexposed part of the intrusive body or within the Belt Supergroup rock units adjacent to the intrusive.

The arcuate feature B, mainly defined by East Fisher Creek and Silver Butte Fisher River, is approximately 16 km northeast of the exposed part of the intrusive along the Vermilion River (B, fig. 2). Although the aeromagnetic anomaly is restricted to the general area of the exposures of the intrusive body (B, fig. 5), the related gravity high extends much further to the north and northeast (B, fig. 6a). Whether the extent of the gravity anomaly reflects the presence of the intrusive at depth in the northeast or is due to the presence of the higher density Prichard and Ravalli lithologic units is not clear.

The elliptical feature C that surrounds the buried quartz porphyry situated beneath Mount Silcox (Harrison and others, 1982) is outlined by segments of the Thompson River, West Fork of Thompson River, Graves Creek, and Clark Fork (C, fig. 2). The aeromagnetic total intensity high and the Bouguer gravity low (C, figs. 5 and 6a, respectively) generally are offset to the south of the elliptical area.

Another large, roughly circular feature was mapped on the larger-scale images but was not identified on the 1:2,500,000-scale image mosaics. This feature is approximately centered around Kellog, Idaho and encompasses a large part of the Coeur d'Alene mining district (D, fig. 2). The streams that outline this area are the Coeur d'Alene River on the north and northwest, Beaver Creek on the east, and the East Fork on the southwest; the southeastern part is defined by a series of ridges that changes orientation from east at the southern boundary to northeast near Striped Peak. The rock units within this feature are chiefly argillite, siltite, quartzite, and minor carbonate rocks of the Belt Supergroup (Griggs, 1973; Harrison and others, 1981).

Arcuate feature D appears to be mainly the topographic expression of northwest-trending, doubly plunging anticlines that are displaced right-laterally by the Osburn-Ninemile fault and to other faults that are peripheral to the feature (fig. 13). Although the dominant trend of faults in this area is west to west-northwest, which reflect the prominence of the Osburn-Ninemile zone, north- and north-northwest-trending faults are prominent along the eastern and northeastern borders (fig. 13). Along the northern border of this arcuate feature northwest- and, locally, west-trending faults dominate. Notably arcuate west-trending faults are present along the southern and southwestern borders (Griggs, 1973; Harrison and others, 1981). Together, the trends of faults and bedding appear to have guided the course of erosion along the streams that outline this arcuate feature. This area also has the highest areal density of linear features in the study area (fig. 14). A large gravity anomaly having a similar location and outline is present in the eastern part of the area (D, fig. 6a), and a slightly smaller aeromagnetic total intensity low anomaly is within the eastern part of the area (D, fig. 5). However, both anomalies extend east of the

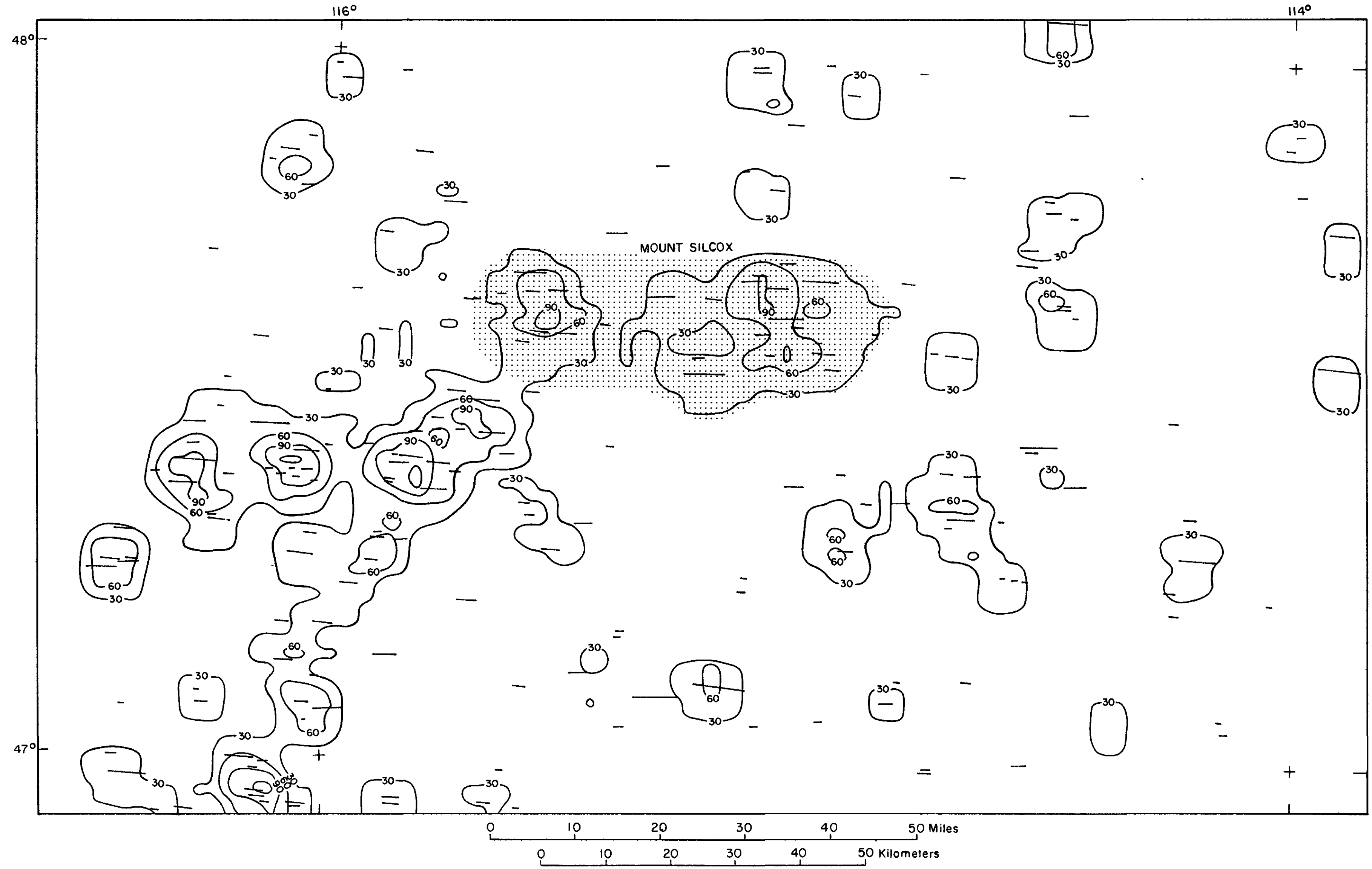


Figure 11.--Linear features map and contour map of N89°E- and N82°-88°W-trending linear features in the Wallace, Id.-Mont. 1° x 2° quadrangle. Stipple pattern indicates location of the Mount Silcox concentration of linear features.

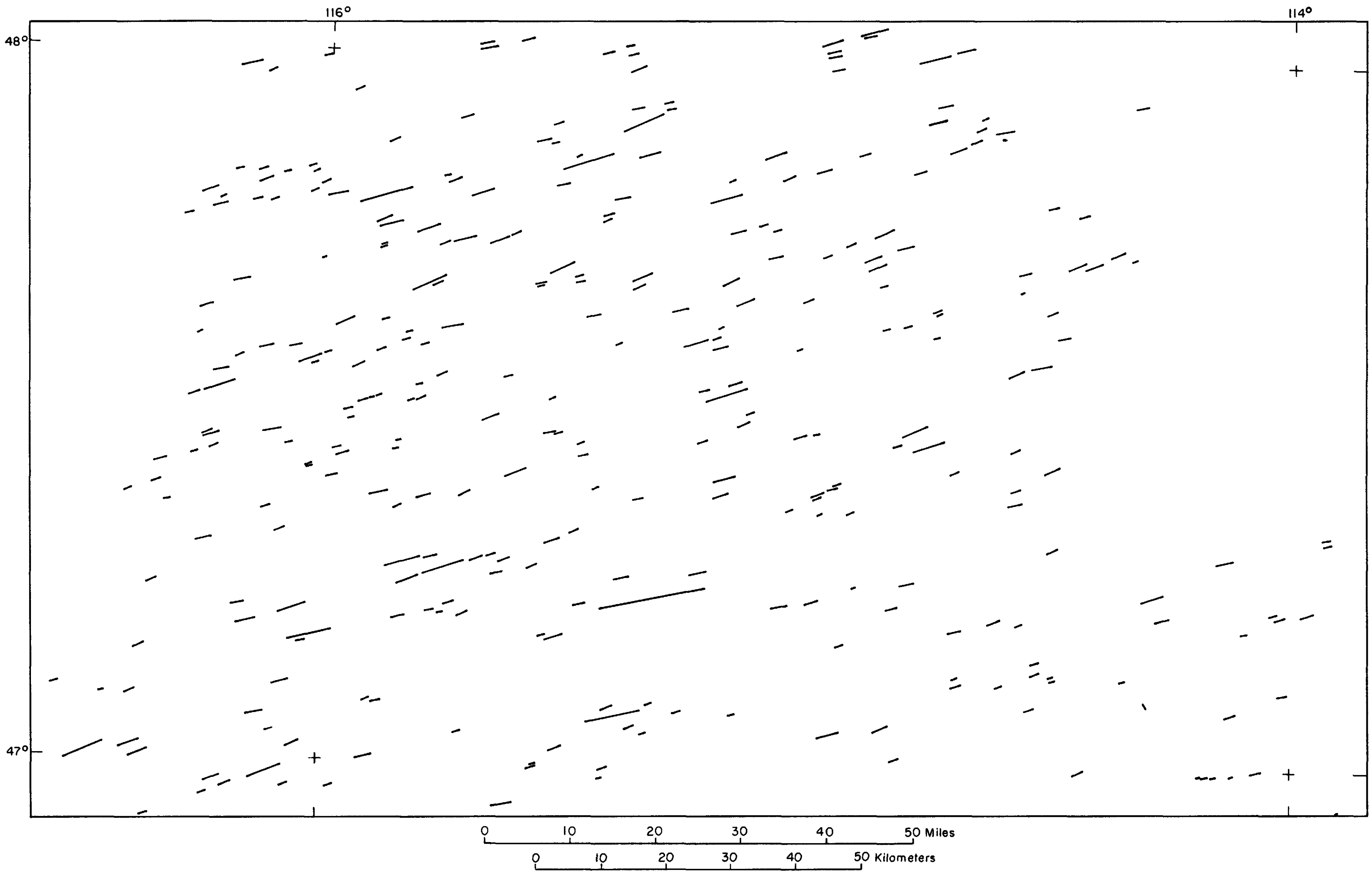


Figure 12.--Map of linear features trending N65°-80°E in the Wallace, Id.-Mont. 1° x 2° quadrangle.

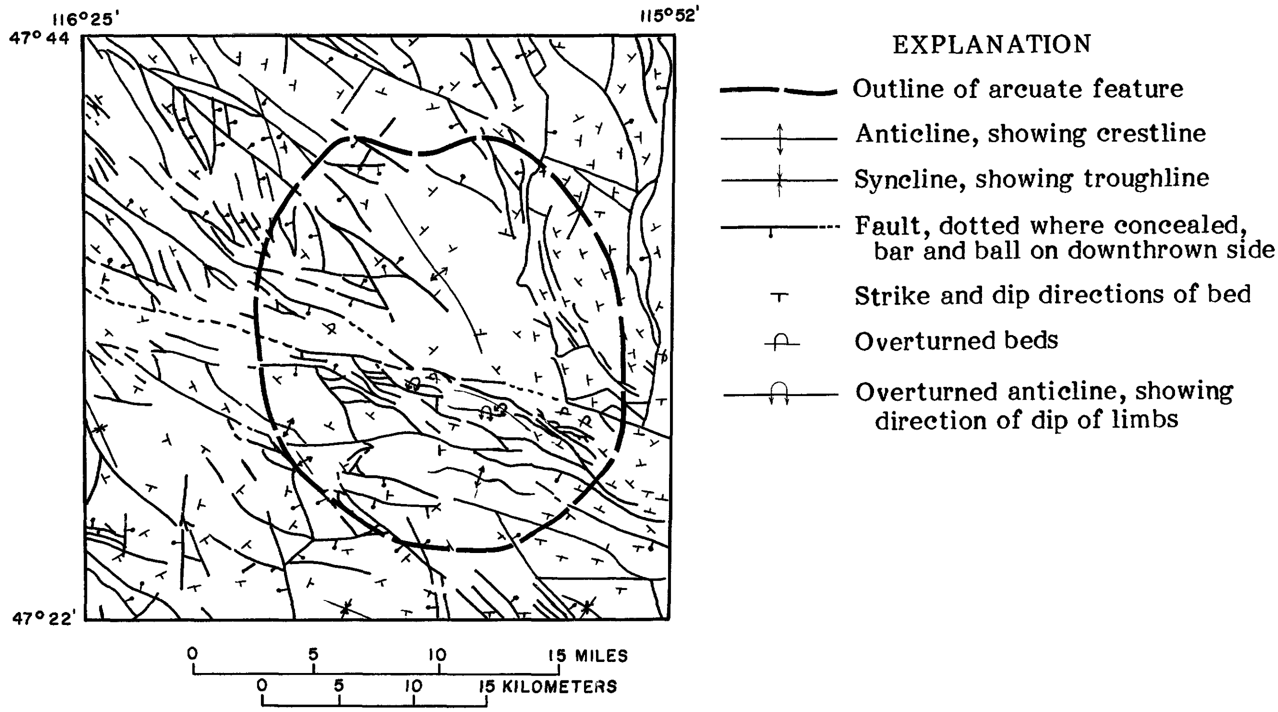


Figure 13.--Map showing the patterns of faults and bedding attitudes within the arcuate feature (D, fig. 2) centered at Kellogg, Id. (Griggs, 1973; Harrison and others, 1981).

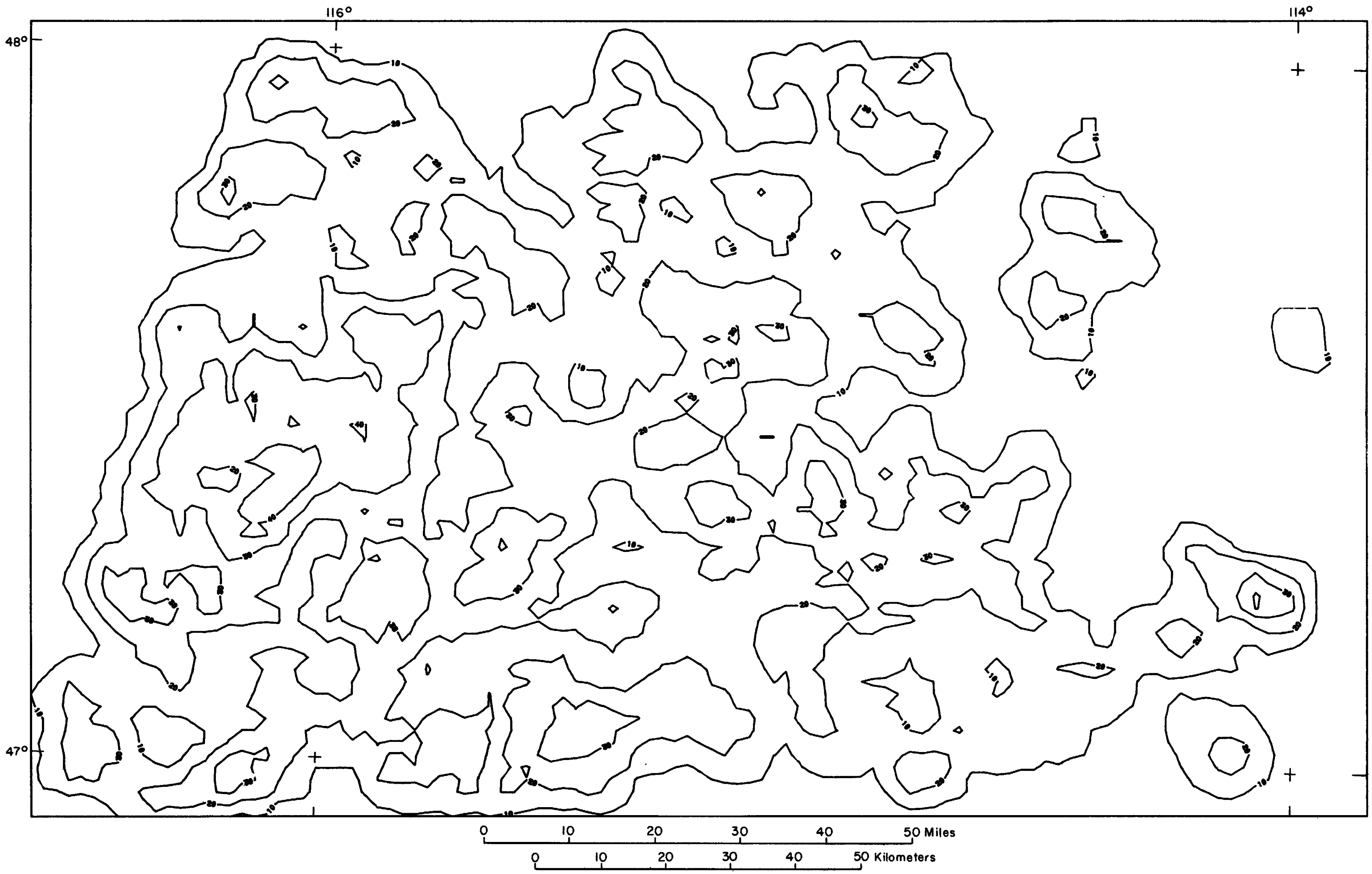


Figure 14.--Contour map showing the areal concentration of linear features.

circular feature. Detailed gravity and aeromagnetic data are needed in the western part of this feature in order to determine the underlying cause for the structural pattern shown in figure 13.

All the other arcuate features (fig. 2) are considerably smaller and most appear to be erosional remnants. Only one of these features may have gravity and aeromagnetic anomalies associated with it (E, figs. 5, 6a, and 2) that might recommend more detailed studies.

The substantially greater extent of the arcuate features, in at least one direction, than the gravity and aeromagnetic anomalies related to the three known intrusives is interesting, because this may indicate that the area of influence in the form of fracturing may be larger than the immediately adjacent host rocks. The attitudes of faults and bedding, as well as fractures not shown on the geologic maps (Griggs, 1973; Harrison and others, 1981), may also account for the large circular feature located in the Kellog, Idaho area (D, fig. 2), but the underlying cause for the structural pattern may be the emplacement of a subjacent intrusive body.

DISTRIBUTION OF LINEAMENTS, CONCENTRATIONS OF LINEAR FEATURES, AND ARCUATE FEATURES IN RELATION TO MINERAL FAVORABILITY

Comparison of the areal distributions of the lineaments, concentration of linear features, and arcuate features with areas judged to have high favorability for mineral occurrences (figs. 15 and 16) shows excellent agreement in some areas, but the correlation is not consistent. Lithologic, structural, geochemical, and geophysical data were evaluated by Harrison and others (1982) in order to rank areas according to their favorability for the occurrence of the types of mineral deposits considered to be potentially important in the quadrangle.

The remote sensing results were used in assessing the potential of mesothermal vein deposits because of the presence of such deposits at the intersections of the Thompson River and Wallace lineaments with the Mount Silcox concentration of linear features at Mount Silcox and Sex Peak, respectively. Moreover, arcuate features are present at both intersections (fig. 17). The relationship between favorability for mesothermal and other deposits and the lineaments, linear features, and arcuate features is less clear where the degree of coincidence of these features is lower than that near Sex Peak and Mount Silcox. Positive correlations, which is where favorable ground corresponds with one or more of these features, appear to be present in the following areas:

1. The juncture of the Vermilion River lineament (VR) with the arcuate features A and B (figs. 15 and 17) presumably reflects a subjacent intrusive body located north of the exposed intrusive.
2. High favorability was noted in the region where the Wallace lineament (W) and arcuate feature D intersect (figs. 15 and 17). Although the region is generally parallel with the Lewis and Clark fault zone, a northeast grain is evident near the gem stocks and in the northeast (fig. 15) (Harrison and others, 1981).
3. In the southeastern part of the quadrangle, most highly favorable areas are located along the Osburn-Ninemile fault zone, but an elongate area trends northeastward along the Sloan-Cedar Creek lineament (SC, figs. 15 and 17) (Harrison and others, 1981). In addition, the only area of moderately favorable ground in the south-central part of the quadrangle is locate along this lineament (SC, figs. 15 and 17).

A possible negative relationship may be present between the Thompson River lineament and favorability for mesothermal vein deposits (Harrison and others, 1982). This lineament is generally coincident with a favorability saddle that separates regions of high favorability to the northwest and southeast along the Lewis and Clark fault zone. However, the northwestern terminus of the southeastern area of high favorability (inside arcuate feature C) has a prong that extends north-northeastward along the margin of this lineament (TR, figs. 15 and 17).

Although a small area with high favorability is located in the vicinity of the Nemote and Barrette Creek lineaments (NC and BC, fig. 15), its pronounced northwest trend suggests that the Osburn-Ninemile fault zone is the important structural feature. The Renfro Peak lineament does not exhibit a good correlation with favorability for mesothermal vein deposits (RP, fig. 15).

Areas that are favorable for porphyry molybdenum-tungsten deposits are scattered throughout the western half of the quadrangle (fig. 16) (Harrison and others, 1982). The two areas having the highest favorability are located where the Wallace (W) and Thompson River (TR) lineaments intersect the Mount Silcox (MS) concentration of linear features (fig. 16). Although areas of moderate and low favorability occur along all the other lineaments in this part of the quadrangle, the lineaments encompass most of the area and several favorable areas lie outside of the lineament boundaries. Thus, here, as with mesothermal vein deposits, the intersections of the Thompson River and Wallace lineaments with the Mount Silcox feature show the best correlation with favorability. The relationship between the lineaments and porphyry molybdenum-tungsten favorability is not clear elsewhere.

The single epithermal silver-vein deposit known in the quadrangle is associated with a Tertiary volcanic complex located in the northeastern part of the quadrangle (Harrison and others, 1982). This complex is situated at the northeastern end of the Thompson River lineament as delineated on the 1:2,500,000-scale mosaic (fig. 1). An arcuate feature (fig. 2) is located about 6 km northeast of the volcanic complex, but it does not appear to be related to the volcanic activity.

Little evidence has been noted to suggest a relationship between the distribution of the features identified in the Landsat images and strata-bound lead-silver-zinc favorability. Similarly, the favorability of streams for placer gold deposits does not show any obvious relationship with these features, except that many of the most promising drainages are northeast oriented.

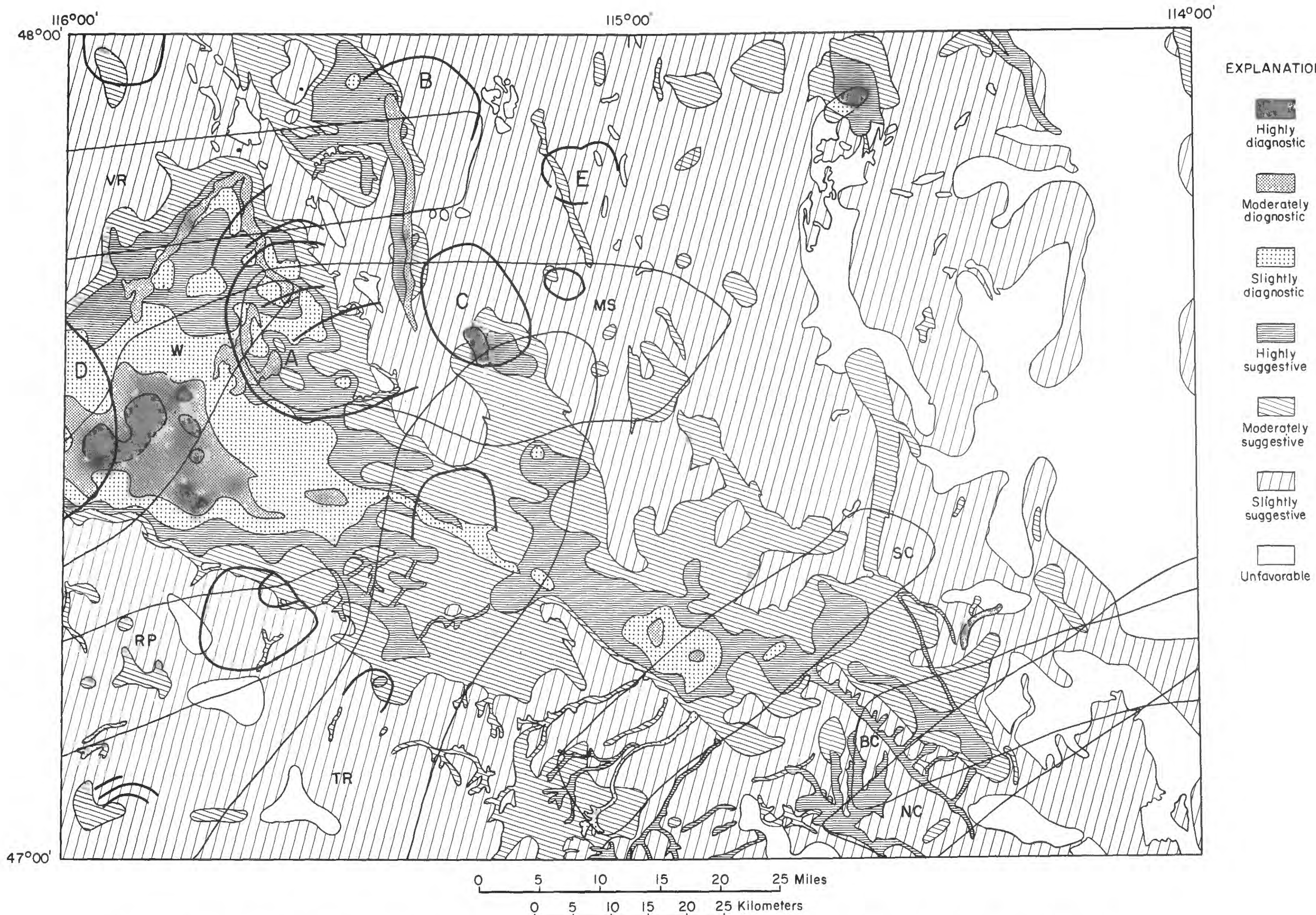


Figure 15.--Favorable-ground map for mesothermal vein deposits (Harrison and others, 1982). The map presents information about the probability of ore deposit occurrences. Explanation of symbols used on map: W- Wallace lineament; TR- Thompson River lineament; RP- Renfro Peak lineament; NC- Nemote Creek lineament; BC- Barrette Creek lineament; VR- Vermilion River lineament; MS- Mount silcox concentration of linear features. A, B, C, D, and E correspond to arcuate features discussed in the text.

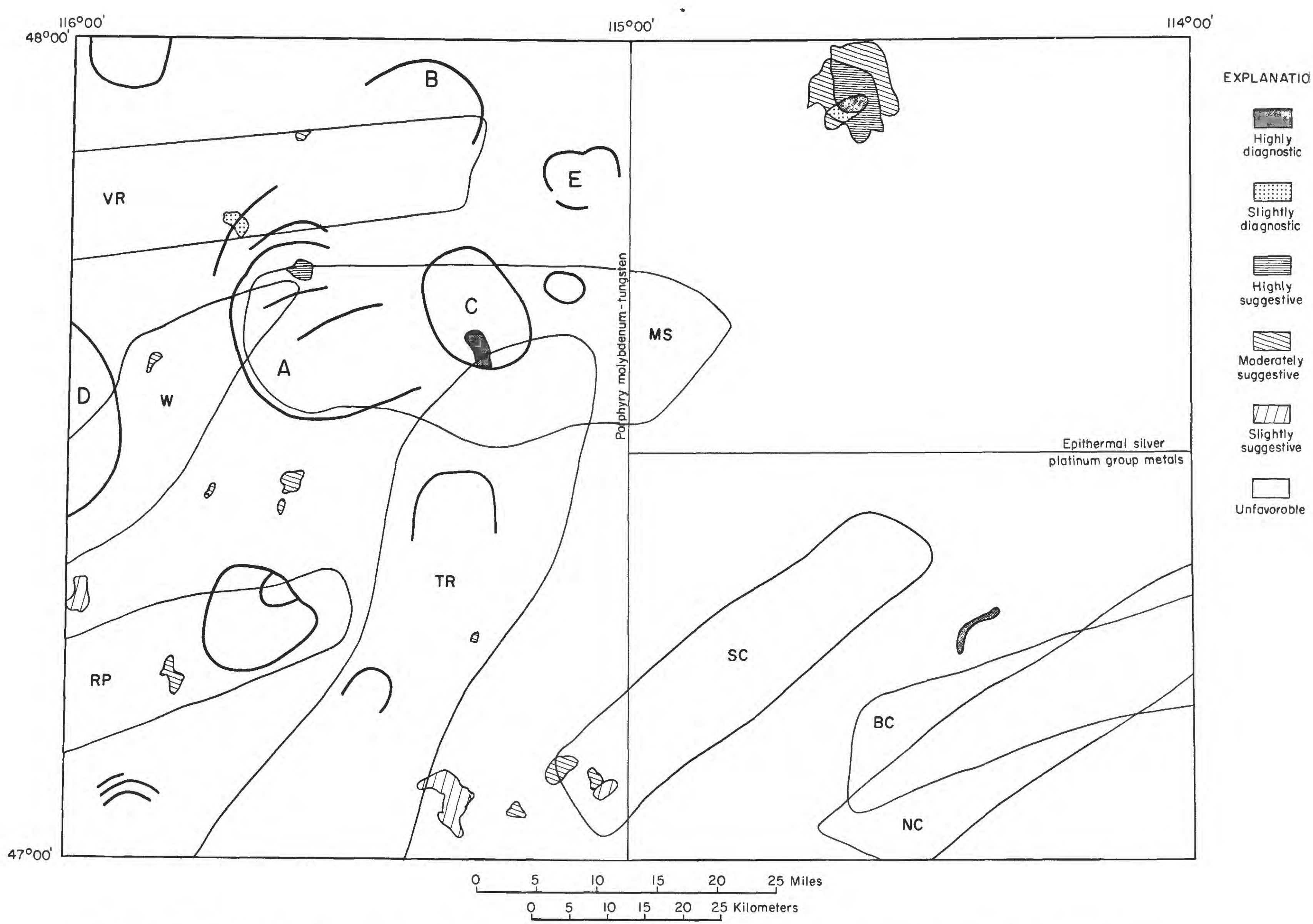


Figure 16.--Favorable-ground map for epithermal silver, porphyry molybdenum-tungsten, and platinum group metals (Harrison and others, 1982). The map presents information about the probability of the ore occurrences. Explanation for symbols used on map: W- Wallace lineament; TR- Thompson River lineament; RP- Renfro Peak lineament; NC- Nemote Creek lineament; BC- Barrette Creek lineament; VR- Vermilion River lineament; MS- Mount Silcox concentration of linear features. A, B, C, D, and E correspond to arcuate features discussed in the text.

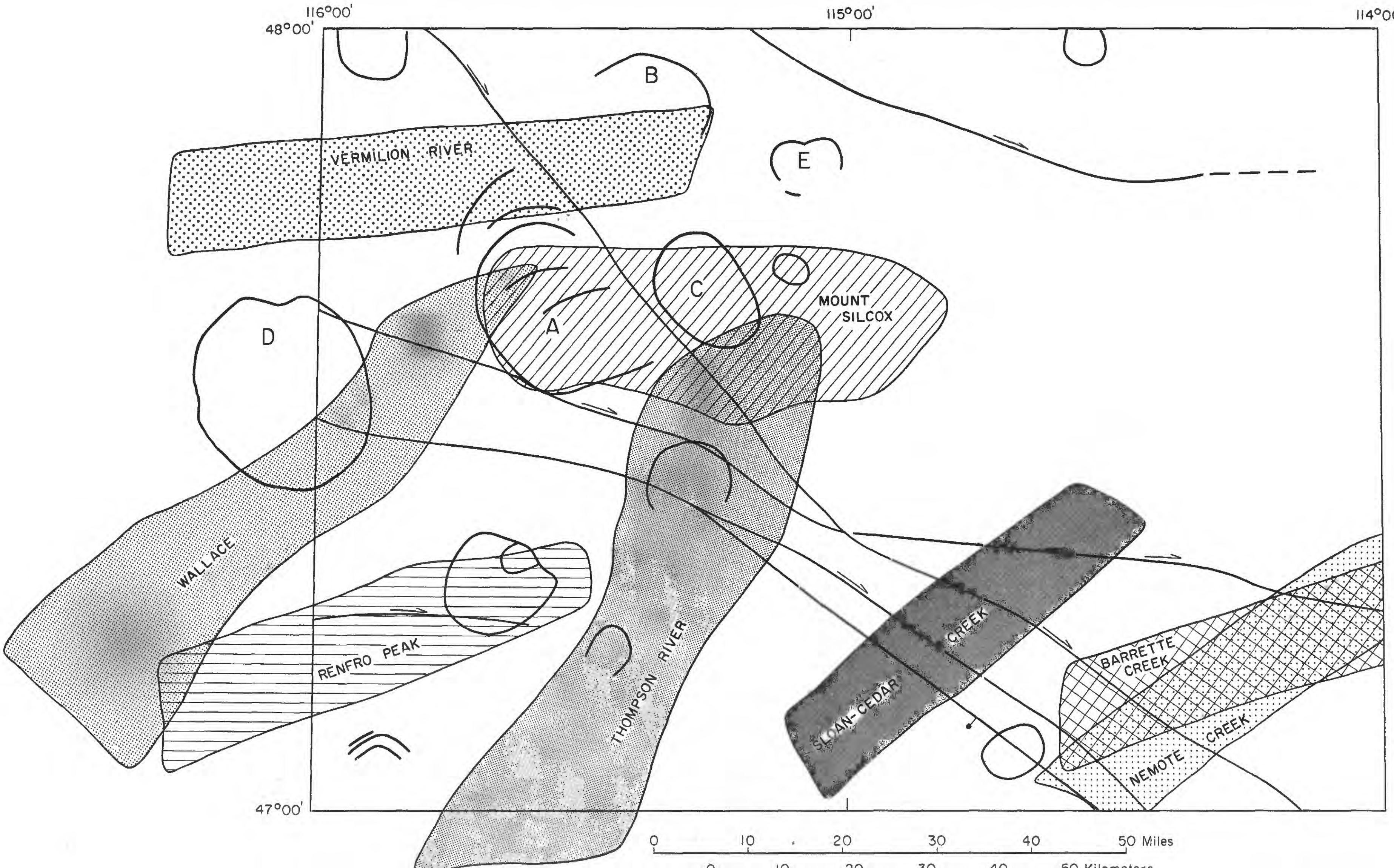


Figure 17.--Map showing areas where major faults, lineaments, concentrations of linear features, and arcuate features intersect in the Wallace, Id.-Mont. $1^{\circ} \times 2^{\circ}$ quadrangle. A, B, C, D, and E correspond to arcuate features discussed in the text.

INTERPRETATION

In considering their origin and possible relevance to the deposition of ore deposits, the following characteristics of the generally northeast-oriented lineaments must be kept in mind:

1. About one-third of the linear features comprising the lineaments, except for the Renfro Peak lineament, are linear stream segments, and most of the remainder are linear ridges which are typically bounded on at least one side by a linear stream segment.
2. Mapped faults are not commonly coincident with these linear features.
3. Generally, the lineaments appear to be continuous for considerable distances south and southwest of the quadrangle, and they cross the major right-lateral strike-slip faults without perceptible disruption or deflection, except for the Renfro Peak lineament which appears to terminate at the Lewis and Clark fault.
4. In the second vertical derivative gravity map (fig. 6b), the lineaments are roughly coincident with or parallel to boundaries that appear to separate crustal blocks having either different depth or perhaps, compositions.

These characteristics suggest that these lineaments represent zones of concentrated fractures along which little or no displacement has occurred. The fractures must have occurred prior to the development of the modern drainage system, but apparently subsequent to the last substantial right-lateral movement along the strike slip faults. The Thompson River and Vermilion River lineaments bound blocks in the Cabinet Mountains that were the sites of numerous glaciers during the Pleistocene epoch (Alden, 1953). The Thompson River lineament separates the southern block of the Cabinet Mountains from lower terrain in the southeast, and the Vermilion River lineament bounds the block of elevated terrain on the northwest; the Clark Fork River lies along the southwestern boundary. Another elevated block of the Cabinet Mountains is situated to the northwest of the Vermilion River lineament. The northeastward projection of the Vermilion River lineament is coincident with several normal faults and the southern limit of the continental ice sheet (Alden, 1953). According to Alden, the region southeast of the ice sheet was too low for the formation of glaciers and moderately high mountains blocked the southward advance of the ice sheet. The region to the south may have been elevated structurally, although not as high as the Cabinet Mountains, and the Vermilion River lineament may be an expression of the disrupted zone.

The Nemote Creek and Barrette Creek lineaments may be components of a broader structural zone that also influenced the topographic configuration during the Pleistocene glaciation. North of Missoula, mainly in the Choteau $1^{\circ} \times 2^{\circ}$ quadrangle, the southern part of the Mission Range is bounded by northeast- , as well as northwest-oriented fault scarps. Although these features are 10 to 20 km southeast of the Nemote Creek and Barrette Creek lineaments, a broader northeast-trending deformed zone is suggested by the presence of an alignment of gravity anomalies (Hildebrand and others, 1982) that extend southwestward from the Bearpaw Mountains in north-central Montana, across the southeastern corner of the Wallace quadrangle, and into central Oregon.

The pre-Pleistocene history of the lineaments is much more difficult to determine, but the northeast alignment of the gem stocks along the Wallace lineament indicate that this presumed fracture zone provided the conduits for the ascending magma approximately 110 Ma (Harrison and others, 1981). In the vicinity of Sex Peak, both the aeromagnetic and gravity maps (Kleinkopf and others, in press) are dominated by northeast trends associated with the partially exposed 100-million-year-old intrusive body (Harrison and others, 1981). Structural control on this intrusive exposed in the Vermilion River Canyon is not clear, but the east-northeast-orientation of this lineament is not as evident as north-northeast and northwest trends in the aeromagnetic (fig. 5) and gravity (fig. 6a) maps (Kleinkopf and others, in press).

All the characteristics noted for the generally northeast-oriented lineaments also apply to the Mount Silcox concentration of linear features, except that its extent is limited to the west-central part of the quadrangle and it is not expressed as well in the second vertical derivative gravity map (fig. 6b). However, this concentration appears to have influenced the configurations of the intrusive bodies at Sex Peak and Mount Silcox. An easterly grain is, as mentioned previously, evident in the aeromagnetic map pattern at Sex Peak, whereas the gravity anomaly expressing the 49.2-million-year-old buried porphyry beneath Mount Silcox (Harrison and others, 1981) is dominantly east-trending. We believe that the occurrence of the Mount Silcox and Sex Peak intrusive bodies at the intersections of the Mount Silcox concentration with the Thompson River and Wallace lineaments is probably more than coincidental.

The relationships between some of the lineaments and Cretaceous intrusive rocks suggest that at least locally the fractures which the lineaments appear to represent were formed prior to or concurrently with the emplacement of the intrusives. Yet, the lineaments are not offset by the right-lateral strike-slip faults which were active during Tertiary time (Harrison and others, 1974). One possible explanation for this apparent enigma would be the existence of a regional conjugate shear system as has been proposed for the Nevada portion of the Great Basin (Shawe, 1965; Rowan and Wetlaufer, 1981), but the left-lateral strike-slip displacement anticipated along the northeast-trending lineaments has not been observed. Alternatively, these features may have a more deep-seated origin than the transcurrent faults, perhaps reflecting discontinuities in the upper mantle.

CONCLUSIONS

Analysis of linear features mapped on digitally processed Landsat MSS images of the Wallace $1^{\circ} \times 2^{\circ}$ quadrangle indicates the presence of seven generally northeast-oriented lineaments, one east-trending concentration of linear features, and 13 arcuate features. Examination of Landsat MSS mosaics of this part of the western United States shows that these lineaments extend for considerable distances to the west, south, and southwest of the quadrangle. The longest feature, the Thompson River lineament, may transect the entire quadrangle and the Pullman, Wash. $1^{\circ} \times 2^{\circ}$ quadrangle to the southwest, a total distance of roughly 250 km.

Most of the linear features comprising the lineaments and the concentration of linear features are distinctly linear stream segments and, to a lesser extent, linear ridges bounded by linear stream segments. The high areal density of aligned stream segments along the lineaments is readily apparent on the accompanying map. This relationship, along with the general lack of coincidence of mapped faults with these linear features, suggests that the linear stream segments were developed along zones of fractures. Some of these fracture zones, such as the Thompson River and Vermilion River lineaments, appear to have bounded blocks that were elevated differentially during Pleistocene glaciation. Another indication of the youthfulness of these lineaments and the fractures that they apparently reflect is the fact that they transect the major Tertiary right-lateral strike-slip faults without perceptible deflection.

Expressions of the lineaments in gravity maps of the quadrangle and this part of the western United States suggest that these morphological features are expressions of substantially older, extensive crustal flaws. Most of the Cretaceous intrusive bodies in the Wallace quadrangle, which are also marked by arcuate features, occur along these lineaments, and several are parallel to the trend of the related lineament.

The areas where the Mount Silcox concentration of linear features intersects the Wallace and Thompson River lineaments appear to have been favorable sites for the emplacement of intrusive bodies and their associated mineral deposits. The Wallace lineament also appears to have influenced mineralization in the region between Sex Peak and the Lewis and Clark line. Other correlations are apparent along the Sloan-Cedar Creek and Vermilion River lineaments. On the other hand, a paucity of known mineralization occurs elsewhere along the Thompson River lineament, except perhaps in the northeastern part of the quadrangle where the Tertiary epithermal vein deposit is situated at the possible northeast terminus of this lineament. Little or no relationship was noted between the stratabound mineral deposits and the features mapped in the Landsat images.

We conclude that the lineaments and the concentration of linear features are morphological expressions of deep-seated regional fracture zones that have been reactivated periodically since Cretaceous time. They were present during Pleistocene glaciation and subsequent developement of the present drainage system, and appear to provide local conduits for magma that ascended during Cretaceous and, perhaps, Tertiary time. Intersections, particularly those at Sex Peak and Mount Silcox, appear to have provided especially favorable conditions.

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STATISTICAL ANALYSIS OF LINEAMENT DATA

The linear feature data were digitized to facilitate statistical analysis. Straight linear features were digitized by specifying their end points and curvilinear features were digitized as a series of linear segments which were then treated as individual linear features.

The linear-feature data were then analysed statistically in order to determine significant trends on the basis of the frequency distribution of the data (Sawatzky and Raines, 1981), and linear features having statistically significant trends were plotted. Contour maps of the areal density distribution of linear features were produced and used as an aid in determining the locations of lineaments.

For the statistical analysis, the frequency of observation was weighted according to the length of the linear features, because we consider the long features to be of greater importance than the short features. Statistically significant trends were identified by determining the probability that the weighted frequency for each class interval would occur in a uniform population of length-weighted directions. Frequencies near the mean have low significance, and significance increases as the frequencies depart from the mean (Sawatzky and Raines, 1981). Thus, significant maxima and minima have high and low frequencies, respectively, that are far from the frequency mean. Selection of maxima and minima for further analysis is determined by the significance value chosen.

Clusters of statistically significant trends were identified in the broad maximum which is centered around N60°E (fig. 8) using a significance value of 90.4. This value corresponds to length-weighted frequencies of 1666 and 1532 for the limiting boundaries of significant maxima and minima respectively. Four clusters of significant maxima were identified, each being separated by at least two 1-degree intervals that have frequencies of less than 1532 (fig. 8, table 1). On the basis of distribution of significant maxima within three of the four clusters further subdivisions were made (fig. 8, table 1). The N3°-33°E significant maximum was subdivided into two azimuthal ranges (fig. 8), N3°-16°E and N19°-33°E. The justification for this subdivision was the two intervening non-significant intervals (fig. 8). The N65°-80°E significant maximum was also subdivided into two azimuthal ranges (fig. 8), N65°-68°E and N71°-80°E. Again, the basis for the subdivision was two intervening non-significant intervals. The broadest cluster of significant trends extends from N83°-90°E through N60°-89°W. This significant maximum is made up of 1-degree intervals of very high frequencies. It was subdivided on the basis of locations of peaks within the maximum (fig. 8, table 1). The N40°-60°E maximum was not subdivided.

The contouring procedure employed involved counting the number of linear features intersected by a counting cell that was moved incrementally across a gridded map. The increment of movement corresponds to the size of a unit cell of the gridded data. The summations were then normalized to obtain a percentage of the total number of intersections counted for each unit cell. Because the counting cell is larger than the unit cell of the grid, the data are smoothed (Knepper, 1979).

Table 1.--*Azimuthal ranges of statistically significant maxima and subdivisions of these ranges*

Significant Maxima	Width (degrees)	Subdivisions of Maxima
N3°-33°E	31	N3°-16°E
		N19°33°E
N40°-60°E	21	
N65°-80°E	16	N65°-68°E
		N71°-80°E
N83°-90°E, N60°-90°W	38	N83°-85°E
		N89°E
		N82°-88°W
		N68°-75°W
		N63°-65°W