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GEOLOGIC EVALUATION OF MAJOR LANDSAT LINEAMENTS IN NEVADA AND THEIR RELATIONSHIP TO ORE DISTRICTS

by

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and

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This report is preliminary and has not been edited or reviewed for comformity with U.S. Geological Survey standards and nomenclature.

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ABSTRACT

Analysis of diverse geologic, geophysical, and geochemical data shows that eight major lineament systems delineated in Landsat images of Nevada are morphological and tonal expressions of substantially broader structural zones. Southern Nevada is dominated by the 175 km-wide northwest-trending Walker Lane, a 150 km-wide zone of east-trending lineament systems consisting of the Pancake Range, Warm Springs, and Timpahute lineament systems, and a 125 km-wide belt of northeast-trending faults termed the Pahranagat lineament system.

Northern Nevada is dominated by the northeast-trending 75-200 km wide Midas Trench lineament system, which is marked by northeasterly-oriented faults, broad gravity anomalies, and the Battle Mountain heat flow high; this feature appears to extend into central Montana. The Midas Trench system is transected by the Northern Nevada Rift, a relatively narrow zone of north-northwest-trending basaltic dikes that give rise to a series of prominent aeromagnetic highs. The northwest-trending Rye Patch lineament system, situated at the northeast boundary of the Walker Lane, also intersects the Midas Trench system and is characterized by stratigraphic discontinuities and alignment of aeromagnetic anomalies.

Field relationships indicate that all the lineament systems except for the Northern Nevada Rift are conjugate shears formed since mid-Miocene time during extension of the Great Basin. Metallization associated with volcanism was widespread along these systems during the 17-6 m.y. period. However, these zones appear to have been established

prior to this period, probably as early as Precambrian time. These lineament systems are interpreted to be old, fundamental, structural zones that have been reactivated episodically as stress conditions changed in the western United States. Many metal districts are localized within these zones as magma rose along the pre-existing conduits.

INTRODUCTION

Analysis of Landsat Multispectral Scanner (MSS) images of geologically diverse terrains has repeatedly brought to light numerous linear features, the presence of which has been confirmed by analyzing repetitive images. The length of these features varies greatly, from tens to hundreds of kilometers. Although the significance of these features, many previously unknown, has been debated, mounting evidence indicates that a substantial number are directly related to tectonic activity (Isachsen, 1973; Pickering and Jones, 1973; Merifield and Lamar, 1974; O'Leary and others, 1978; Viljoen, 1973; Mohr, 1974; Lathram and Albert, 1974; Wise, 1978; Drahovzal, 1974).

Several factors continue to warrant a cautious approach to identifying and interpreting linear features and regional structure in MSS images. Initial compilation procedures are necessarily somewhat subjective due to differing backgrounds and objectives of interpretors and to technical factors such as quality of the images used, sun angle effects, seasonal influences, etc. (Siegal, 1977). In addition, because detection of faults and fractures depends on topographic enhancement and, less commonly, on brightness contrasts related to abrupt changes in lithology or vegetation, structural features lacking such expression (e.g., many thrust faults) are usually not detectable. Evaluation of the longer and more frequently tectonically related linear features is made difficult by their complex topographic expression, typically a combination of stream valleys, escarpments, ridges, dikes, and only locally exposed faults. On the other hand, some of the linear features that are detected, more typically the shorter ones, are not obvious manifestations of structural deformation.

In spite of these problems, the fact remains that additional structural information is available through careful analysis of MSS images. Combined with the results of geologic mapping and geophysical and geochemical surveys, this information can be valuable in developing regional tectonic frameworks and in formulating mineral exploration and assessment models (Raines, 1978).

Previous Investigations

Linear features have been compiled and studied using MSS images for several parts of Nevada (Liggett and Childs, 1977; Bechtold and others, 1973; Levandowski and others, 1974; Kutina and Carter, 1977; Raynolds, 1976), but the only detailed statewide compilation was conducted by Rowan and Wetlaufer (1973, 1975). Seven major regional lineament systems were delineated in our earlier studies. Since reporting those results (Rowan and Wetlaufer, 1975; Rowan, 1975), several important regional geologic and geophysical studies have been completed. The regional study by Ekren and others (1976) is especially important because they delineated four major east-trending lineaments in south-central Nevada using Landsat images, topographic relief maps, regional geologic mapping, and aeromagnetic data. They interpret these features to be major left-lateral shear zones of Paleozoic or Precambrian age that influenced the distribution of the Tertiary, and perhaps

Mesozoic, igneous rocks with which most of the nearby base and precious metal deposits are associated. Three of these lineaments are generally coincident with those independently delineated by Rowan and Wetlaufer (1975).

Purpose

The purpose of this report is to describe further the regional geologic setting of major lineaments systems in Nevada using diverse geologic, geophysical, and geochemical data and to consider the origin of these features and their influence on the localization of metal deposits in Nevada. The lineament systems are discussed individually using contour maps that show the areal density of faults according to their azimuth, a new simple Bouguer gravity map, a recently compiled total intensity aeromagnetic map of the Great Basin, a heat flow map of the western United States, and the individual and collective distribution of known metal deposits. The sense and age of movement along faults related to the lineament systems are also described as data availability permit. Southern and northern Nevada are discussed separately because the trends of the major lineament systems are significantly different; the results are synthesized for the entire state with emphasis on the occurrence of metal ore deposits.

ANALYSIS OF LINEAMENTS

Linear features greater than 10 km in length were compiled on an MSS band 5 (500-600 μm) image mosaic of Nevada at a scale of 1:1,000,000 (figs. 1 and 2) and were verified as naturally occurring geological features and therefore as lineaments (O'Leary and others, 1977). Shorter linear features were excluded because they have been shown to correlate poorly with known structural features (Rowan and Wetlaufer, 1975). Comparison of lineaments greater than 10 km long with mapped faults shows that 80 percent of the lineaments coincide, at least in part, with known faults, suggesting some structural significance. Correlation of a fault with a lineament was determined on the basis of an approximately parallel trend and a location within roughly 500 m of the related lineament. From these lineaments, major lineament systems have been delineated which are believed to have regional structural significance. These systems were selected on the basis of their regional extent and their correlation with geophysical data and zones of aligned faults. Several of these systems have been documented prior to their definition on Landsat imagery, and more recent publications continue to underscore their existence and significance.

Figure 3 shows the revised version of the lineament systems originally delineated (Rowan and Wetlaufer, 1975). Four revisions have been made: (1) the Ruby Mountains (rm, fig. 3) lineament system has been deleted due to insufficient data at this time; (2) lineament system C, formerly grouped with B, has been distinguished;

Figure 1 - Landsat image mosaic (uncontrolled) of Nevada. Prepared by Aerial Photographers of Nevada, Reno, Nevada, using MSS band 5 (0.6 - 0.7 μm) images recorded during September and October 1972.

Figure 2 - Map showing correlation of major lineaments ($\geq$10 km length) with faults shown on the Geologic Map of Nevada compiled by Stewart and Carlson (1974) (Rowan and Wetlaufer, 1975).

Figure 3 - Landsat MSS band 5 image mosaic of Nevada showing locations of major lineament systems (black letters): A, Walker Lane; B, Pancake Range; C, Warm Springs; D, Timpahute; E, Pahranagat; F, Midas Trench; G, Northern Nevada Rift; H, Rye Patch. Mountain ranges, lakes, and towns referred to in the text are shown in white letters: ar, Antelope Range; bf, Buffalo Range; cl, Caliente; cm, Cortez Mountains; cr, Clan Alpine Range; dm, Desatoya Mountains; em, Excelsior Mountains; er, East Range; gr, Groom Range; hc, Hot Creek Range; hi, Hiko Range; hr, Humboldt Range; im, Independence Mountains; jm, Jarbidge Mountains; kr, Kawich Range; lk, Lovelock; lm, Lake Meade; lv, Las Vegas; mc, Mountain City; mm, Meadow Valley Mountains; mr, Monitor Range; mt, Midas; od, Owyhee Desert; pa, Pahranagat Range; pl, Pyramid Lake; pr, Pah Rah Range; rm, Ruby Mountains; sl, Stillwater Range; sm, Shoshone Mountains; sr, Sonoma Range; tm, Tuscarora Mountains; tr, Trinity Range; ty, Toiyabe Range; vr, Virginia Range; wh, West Humboldt Range. Mosaic prepared by Aerial Photographers of Nevada, Reno, Nevada.

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(3) lineament system E has been added; and (4) lineament system D has been extended 85 km eastward in agreement with its portrayal by Ekren and others (1976). Lineament C is not shown in figure 2 because, as initially delineated, component segments were less than 10 km in length (Rowan and Wetlaufer, 1975). Nevertheless, we felt in 1975 and continue to feel now that the lineament is so distinctive that it merits recognition. Thus, we now recognize eight major lineament systems in Nevada.

One approach to determining the structural origin of these lineament systems is to examine the areal distribution and trends of faults mapped in Nevada. A concentration of faults would be expected along those major lineament systems which do represent zones of crustal deformation. Trends and senses of movement of the faults along the lineament systems, as well as field evidence reported by other workers, have been used to infer regional stress conditions that prevailed during post-mid-Miocene time.

A series of contour maps showing the statewide areal density of faults was prepared using the following estimated azimuthal ranges: N10°W-N10°E; N10°-30°E; N30°-60°E; N60°-100°E; N60°-80°W; N30°-60°W; and N10°-30°W. Selection of these ranges was based on the trends of the major lineament systems. Because delineation of the faults was achieved visually on the Geologic Map of Nevada (Stewart and Carlson, 1974), the following less specific azimuthal ranges are used throughout this paper: north, north-northeast, northeast, east to east-northeast, west-northwest, northwest, and north-northwest, respectively. Faults were counted for each azimuthal range in contiguous 1000 sq. km

Figure 4 - Contour maps showing the areal density of faults shown on the 1:500,000 scale Geologic Map of Nevada (Stewart and Carlson, 1974) and the major lineament systems delineated in figure 3: (a) northwest-trending, n=1013; (b) west-northwest-trending, n=643; (c) east-to-east-northeast-trending, n=1125; (d) northeast-trending, n=1560; (e) north-northeast-trending, n=1260; (f) north-northwest-trending, n=1193; (g) north-trending, n=3040.

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cells; the resulting numbers were converted to percentages of the total number of faults (n, fig. 4) and contoured manually using a 0.2 percent interval; thrust faults were excluded. We recognize the need for a more consistent delineation of the faults with respect to azimuth than can be achieved visually and for certain statistical evaluations such as significance tests of the trends. To these ends, all the faults are currently being digitized. More serious limitations are the obscuring of bedrock faults by alluvium and the variations in the levels of structural detail in the maps used to compile the State geologic map. However, as will be shown in subsequent sections, anomalously high areal densities of faults are evident on a regional scale, in spite of local interruption of these belts by alluvium-filled basins. Analysis of the contour maps is confined to regional trends because of the above mentioned limitations.

Interpretation of the contour maps (fig. 4) with respect to the major lineament systems delineated in this paper must take into account the areal distribution of both the high and low concentrations of similarly trending faults within each map, as well as the trend of the zones of high fault density. Through this approach, we will show not only that the five lineament systems in southern Nevada (A, B, C, D, E, fig. 3) have a structural basis, but also that the three less commonly recognized lineament systems in northern Nevada (F, G, H, fig. 3) are supported by tectonic data.

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Lineament Systems in Southern Nevada

Walker Lane-Las Vegas Shear Zone: The well-documented Walker Lane-Las Vegas shear zone, hereafter referred to simply as the Walker Lane, is a generally northwest-trending zone of right-lateral transcurrent faulting which traverses approximately 600 km, from Pyramid Lake to Las Vegas (pl and lv, respectively, fig. 3) (Gianella and Callaghan, 1934; Locke and others, 1940; Longwell, 1960; Neilsen, 1965; Shawe, 1965; Albers, 1967). On the Landsat mosaic of Nevada (fig. 1), the abrupt disruption of north-to-north-northeast-trending ranges typical of the Basin-and-Range province is readily apparent along the Walker Lane, although only the northern and central parts are represented by distinct lineaments (A, fig. 3) on Landsat images. The two pairs of northwest-trending lineaments making up lineament system A correspond well with right-lateral strike-slip faults mapped by Stewart and Carlson (1974) and Neilsen (1965). In the southern portion of the shear zone, drag in the mountain ranges (north of lv, fig. 3) related to the right-lateral shear is obvious, but no northwest-trending lineaments can be discerned.

The northwest-trending Walker Lane is conspicuous as a broad zone on the contour map showing northwest-trending faults (fig. 4a). It is highlighted by a roughly 175 km wide zone of several isolated areas of high-fault density. The easterly trend of the individual fault concentrations along the central portion of the Walker Lane probably reflects the influence of the other major structural system dominant in southern Nevada, that of east-to-east-northeast-trending structures. High concentrations of northwest-trending faults are generally lacking in the central and northern parts of Nevada, except for a concentration in the northwest corner of Nevada and a northeast-trending concentration southeast of the Ruby Mountains (rm, fig. 3). The concentration in the northwestern corner of Nevada is probably related to a zone of dominantly northwest-trending faults in southern Oregon.

Areas of high density of west-northwest-trending faults (fig. 4b) also fall within the broad zone defining the Walker Lane, although they are sparse along its central part. The conspicuous easterly trend of the west-northwest fault concentrations in southern Nevada further documents the presence of east-trending structures. As with the northwest-trending fault concentrations, the west-northwest-trending fault concentrations are more common in southern than northern Nevada.

Geophysical data are consistent with the presence of a northwest-trending structural zone in southern Nevada. The northern and central parts of the Walker Lane are generally coincident with the broadly arcuate 150-175 km-wide zone (A, fig. 5) of northwesterly-aligned high-frequency aeromagnetic anomalies. These anomalies are related to the distribution of Tertiary calc-alkaline volcanic rocks (Stewart and others, 1977). In the southern part of the Walker Lane, the belt of anomalies is interrupted by the Quiet Zone, a northerly-trending area of uniform, moderately low, total intensity (Stewart and others, 1977). The simple Bouguer gravity map pattern (fig. 6) is characterized by a northwest-oriented region of moderately low anomalies that separates two similarly trending broad lows to the southwest and northwest; the low

Figure 5 - (a) Total intensity aeromagnetic map of Nevada (Zietz, I., written comm.) and major lineament systems shown in figure 3; (b) aeromagnetic map of the Great Basin showing total intensities greater than 2500 gammas (compiled from Mabey and others, in press) and major lineament systems shown in figure 3.

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Figure 6 - Simple Bouguer gravity map of Nevada and adjacent areas (Eaton and others, in press) and major lineament systems delineated in figure 3.

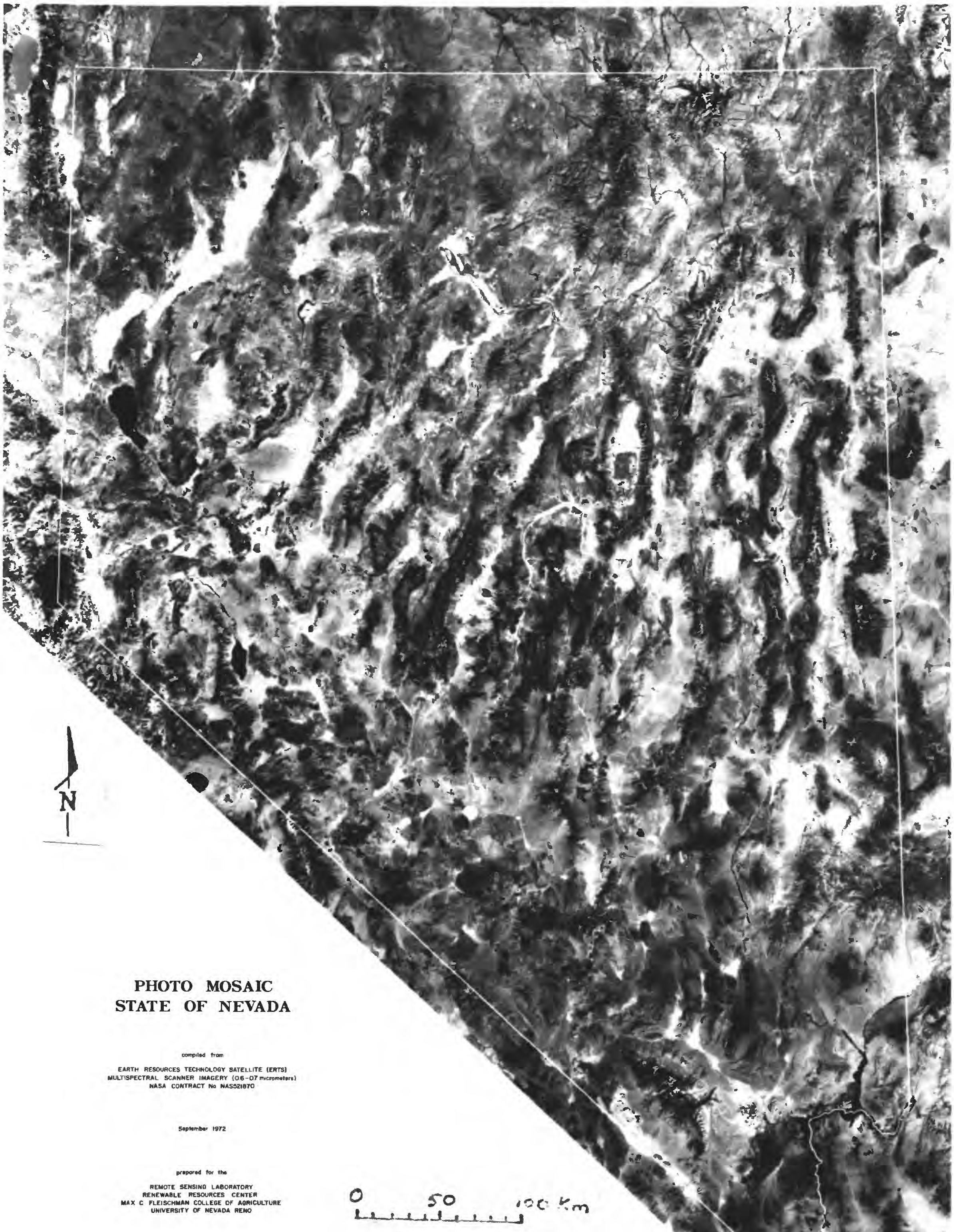
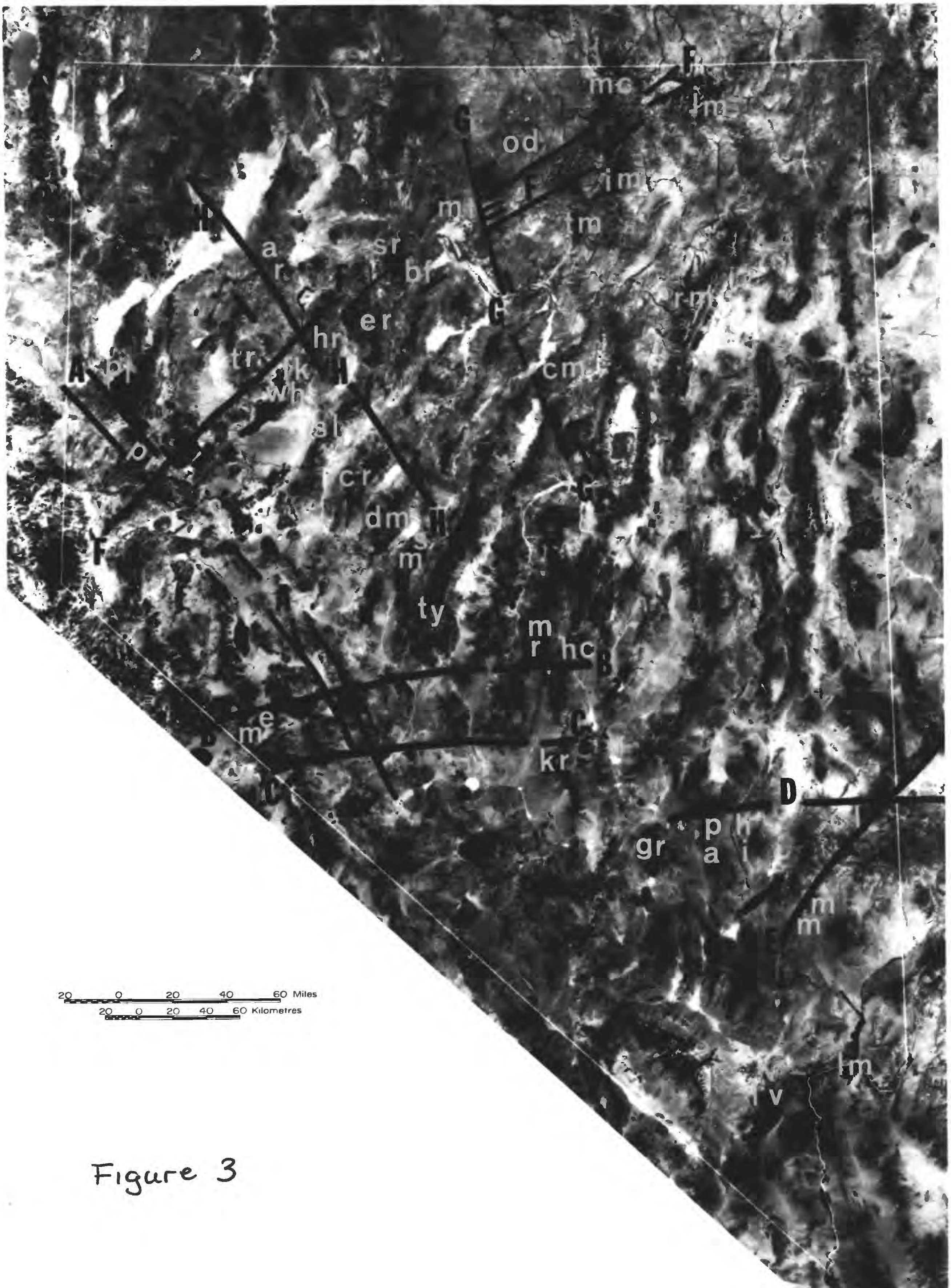

N
0 50 100 Km
PHOTO MOSAIC
STATE OF NEVADA
compiled from
EARTH RESOURCES TECHNOLOGY SATELLITE (ERTS)
MULTISPECTRAL SCANNER IMAGERY (0.6-0.7 micrometers)
NASA CONTRACT No NAS521870
September 1972
prepared for the
REMOTE SENSING LABORATORY
RENEWABLE RESOURCES CENTER
MAX C FLEISCHMAN COLLEGE OF AGRICULTURE
UNIVERSITY OF NEVADA RENO
by
AERIAL PHOTOGRAPHERS OF NEVADA
RENO-STEAD AIRPORT
Original Scale 1:1,000,000

Figure 1


N
ERTS-1
IMAGE MOSAIC
STATE OF NEVADA
by
Aerial Photographers of Nevada
10 0 50 100 km
correlation with fault
extension of fault
no relationship with fault

Figure 2


E
mc
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od
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tm
sr
br
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r
er
hr
G
rm
A
tr
k
H
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m
r
hc
B
e
m
C
B
kr
C
D
p
h
gr
a
m
m
lm
v
20 0 20 40 60 Miles
20 0 20 40 60 Kilometres

Figure 3

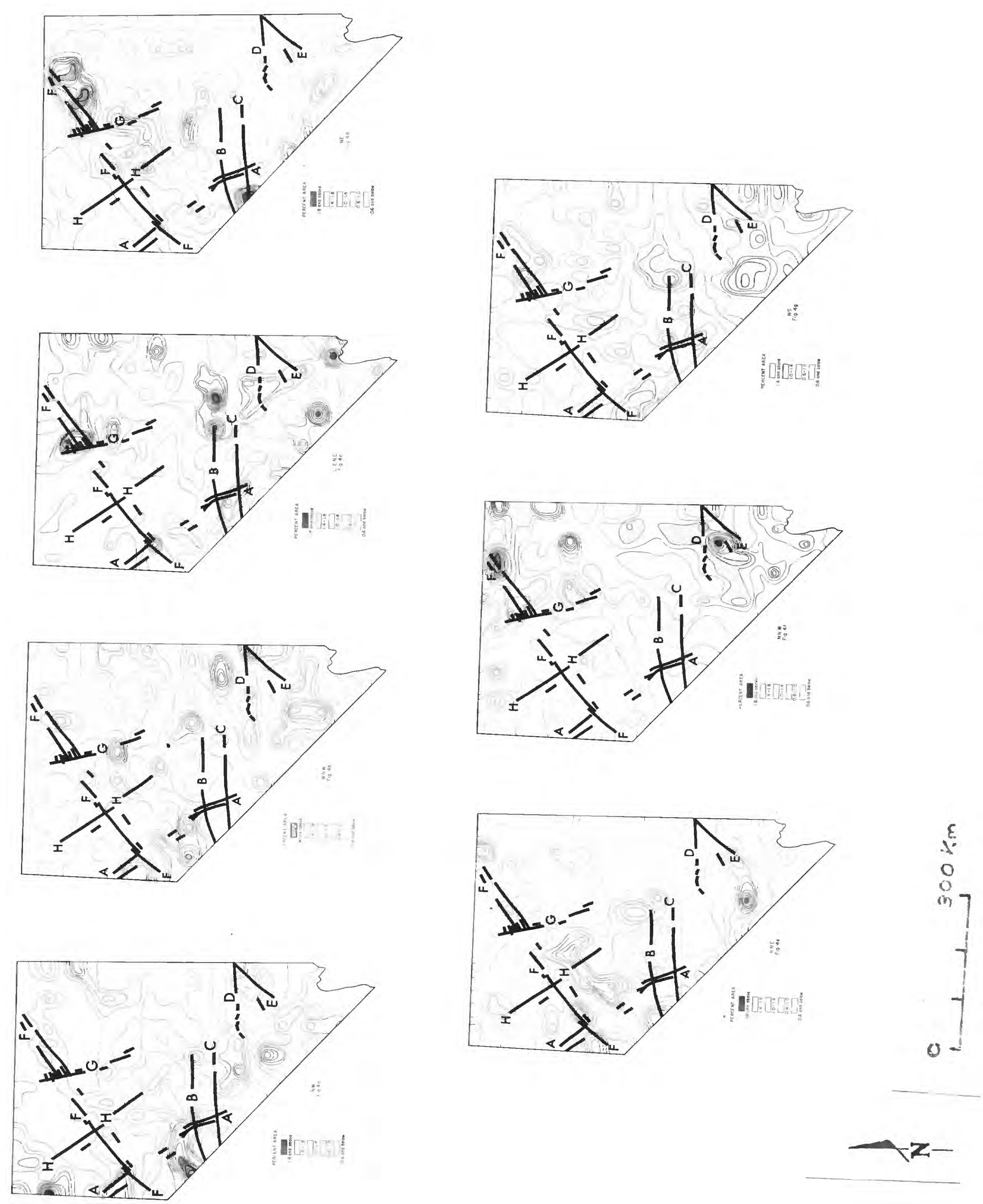

Figure 4


120°
119°
118°
117°
116°
115°
41°
40°
39°
38°
37°
36°
A
A
A
B
C
D
E
F
F
F
G
H
H
GAMMAS
2500 and above
2400 - 2500
2300 - 2400
2300 and below
20 0 20 40 60 Miles
20 0 20 40 60 Kilometres

Fig. 5(a)

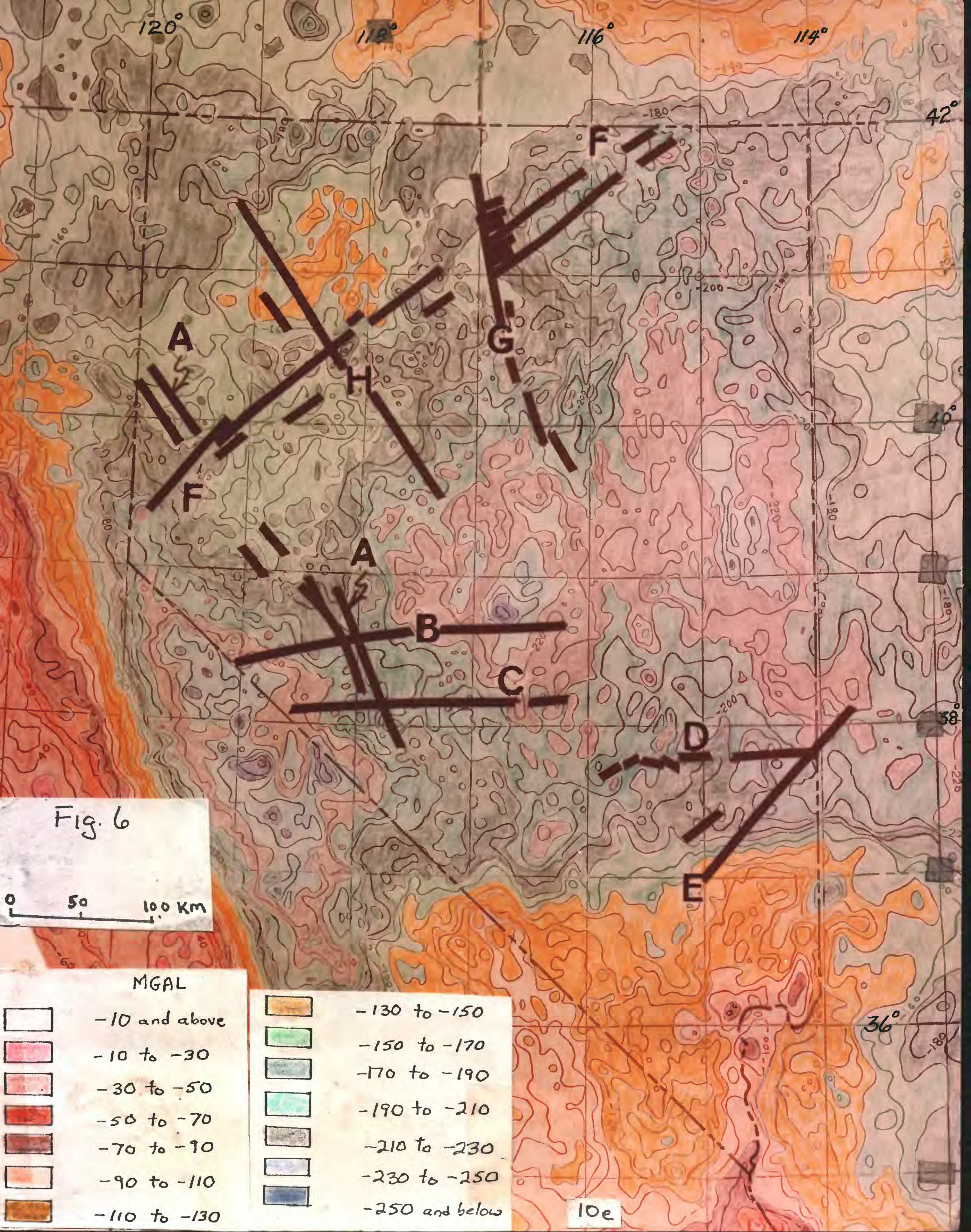
120°
118°
116°
114°
42°
40°
38°
36°
A
A
B
C
D
E
F
F
G
H
0 50 100 Km
MGAL
-10 and above
-10 to -30
-30 to -50
-50 to -70
-70 to -90
-90 to -110
-110 to -130
-130 to -150
-150 to -170
-170 to -190
-190 to -210
-210 to -230
-230 to -250
-250 and below

Fig. 6

to the southwest is probably related to granitic rocks in the Sierra Nevada and White Mountains.

Although the Walker Lane shear zone has clearly been the site of post-basin-range faulting, the bending and major right-lateral movement were essentially over by early-or middle-Miocene time (Albers, 1967). Thickness variations in late Precambrian and Paleozoic strata in southeastern Nevada suggest a Precambrian age for this transcurrent fault zone (Stewart and others, 1968).

East-Trending Lineament Systems: Two east-to-east-northeast-trending lineament systems (B, C, fig. 3) transect the Walker Lane and the northerly-trending basins and ranges (Rowan and Wetlaufer, 1975). Both of these lineament systems disrupt and locally terminate the ranges. The northern lineament system (B, fig. 3) corresponds with the Pancake Range lineament described by Ekren and others (1976). Cook and Montgomery (1974) describe an east-trending structural zone in Utah that may be an eastward extension of the Pancake Range lineament (Ekren and others, 1976). The southern lineament system (C, fig. 3) generally corresponds with the Warm Springs lineament (Ekren and others, 1976). Rowley and others (1978) point out a probable extension of the Warm Springs lineament into Utah for 190 km, calling it the Blue Ribbon lineament. A similarly trending lineament 30 km to the north, the Pritchard Station lineament (Ekren and others, 1968, 1976), was not delineated in this study because it was identified on the basis of aeromagnetic patterns and has very little topographic or tonal expression. A third east-trending lineament system (D, fig. 3) is made up of a group of five east-trending lineaments, measuring a total of 70 km along the northern margins of the Groom, Pahranagat, and Hiko ranges (gr, pa, and hi, respectively, fig. 3), plus an 85 km-long eastern segment added since initial recognition of this lineament system (Rowan and Wetlaufer, 1975). These lineaments comprise the Timpahute lineament system noted by Ekren and others (1976). The full horizontal extent (roughly 350 km) of the Timpahute lineament is well displayed in the 1:2,500,000-scale Landsat 1 mosaic of the conterminous United States. We use the terminology of Ekren and others (1976) for the southern Nevada lineaments throughout the remainder of this paper.

The Pancake Range lineament (B, fig. 3) coincides with several major east-to-east-northeast-trending faults (Ekren and others, 1976). Near the eastern terminus, substantial stratigraphic displacement of Paleozoic rocks and marked contrast of structural pattern are present across an east-trending fault zone. Westward along the lineament system in the Hot Creek Range (hc, fig. 3), a similarly trending fault disrupts Paleozoic rocks and Tertiary volcanic rocks and bounds a cauldron. Both of these faults are believed to be strike-slip faults, although the sense of movement is not clear (Ekren and others, 1976). East-trending faults have also been documented along the Pancake Range lineament in the Monitor Range (mr, fig. 3) by Ekren and others (1976), and they suspect such faults at the southern terminus of the Toiyabe Range (ty, fig. 3). East-to-east-northeast-trending faults with left-lateral displacement have been mapped in the Excelsior Mountains (em, fig. 3) and the Anchorite Hills to the west along the western part of the lineament system.

The Warm Springs lineament system (C, fig. 3) is marked in the east by a structural discontinuity at the bulbous northern end of the Kawich Range (kr, fig. 3), an apparent resurgent cauldron (Ekren and others, 1976). Here and in the Hot Creek and Monitor Ranges (hc and mr, respectively, fig. 3), Paleozoic sedimentary and Tertiary volcanic rocks commonly terminate abruptly at the lineament; locally, the rocks are brecciated. At the western end of the Warm Springs lineament, numerous east-to-east-northeast-trending faults are present (Stewart and Carlson, 1974). Although the sense of movement appears to be mainly dip-slip on these faults, stratigraphic relationships along the eastern part of the lineament are more consistent with strike-slip movement (Ekren and others, 1976).

The Timpahute lineament system (D, fig. 3) is characterized by east-west alignment of intrusive bodies in several ranges, by contrasting structural patterns on opposing sides of the lineament system, by stratigraphic discontinuities across the feature, and by strike-slip faulting locally (Ekren and others, 1976). The lineament system also lies along the boundary of a large cauldron complex near Caliente (cl, fig. 3).

The areal-density contour map of east-to-east-northeast-trending faults (fig. 4c) provides additional evidence for the regional extent of these structural zones. These faults, like the northwest- and west-northwest-trending faults (figs. 4a and 4b), are much more numerous in southern than in northern Nevada. In southern Nevada, concentrations of east-to-east-northeast-trending faults either fall within the Walker

Lane or along eastern extensions of the Warm Springs and Pancake Range lineament systems (B, C, fig. 4c). Concentrations of northwest-and north-northwest-trending faults lie along the Timpahute system (D, figs. 4a and 4b). Within the central part of the Walker Lane, the trends of the east-to-east-northeast-trending fault concentrations appear to echo the northwest alignment of the Walker Lane; the area of low northwest-trending fault density in the central part of the Walker Lane (figs. 4a and 4b) is filled by east-to-east-northeast-trending-fault highs (fig. 4c). Outside of the Walker Lane, the east trends of these fault density highs reflect the dominance of east-trending structures. In the southern part of the Walker Lane, concentrations of faults with east-northeast trends partially overlap those with northwesterly and north-northwesterly trends. The few concentrations of east-to-east-northeast-trending faults in northern Nevada fall along the eastern border of Nevada and in the Independence and Tuscarora Mountains (im and tm, respectively, fig. 3) at the intersection of lineament systems F and G (fig. 3).

Comparison of the east-trending lineament systems with the aeromagnetic map shows that the broad zone of northwesterly-oriented anomalies denoting the Walker Lane are deflected eastward in the vicinity of the Pancake Range and Warm Springs lineament systems (B and C, respectively, figs. 3 and 5a) (Rowan and Wetlaufer, 1975). In more detailed aeromagnetic maps, similarly trending, local discontinuities are evident, especially along the eastern part of the Pancake Range lineament system (Ekren and others, 1976). However, the Pancake Range and Warm Springs lineament systems have little or no expression in the simple Bouguer gravity map (B and C, respectively, fig. 6).

The Timpahute lineament system (D, fig. 3) mostly lies within a 30 km-wide east-to-east-northeast-trending aeromagnetic low (D, fig. 5a). A similarly aligned group of highs lies 30 km south of the eastern half of the lineament system. One of the steepest gravity gradients in Nevada trends generally east, approximately 60 km south of the Timpahute lineament system (D, fig. 6). Eaton and others (in press) believe that this prominent gradient separates a tectonically and volcanically more active area to the north from a less active region to the south.

The easterly grain of the aeromagnetic map is attributed to the generally east-to-east-northeast distribution of Tertiary volcanic and related rocks in southern Nevada (Ekren and others, 1976; Stewart and others, 1977). Although eruption of these rocks migrated from north to southwest with decreasing age (Stewart and Carlson, 1976; Stewart and others, 1977), pre-existing east-trending structures appear to have controlled the emplacement of intrusive bodies, and easterly-oriented topographic features may have influenced the surfacial distribution of the volcanic rocks (Ekren and others, 1976; Stewart and others, 1977).

The east-trending structures may be substantially older than Tertiary and may be as old as Precambrian, because similar trends in Utah, northern Colorado, and southern Wyoming have been related to Precambrian lithologic variations and tectonic features (Zietz and others, 1969; Stewart and others, 1977). In southern Nevada, the east-trending structures lie near the northern limit of Precambrian crystalline rocks (Zartman, 1974) (Fig. 7); such trends are only locally expressed in northern Nevada where outcrops of Precambrian crystalline rocks are generally absent.

Pahranagat Lineament System: Tschanz and Pampeyan (1961) mapped a zone of several post-Miocene northeast-trending left-lateral strike-slip faults in the Pahranagat Range (pa, fig. 3), which were later identified as the Pahranagat shear system (Tschanz and Pampeyan, 1970; Liggett and Ehrenspeck, 1974). We propose that the Pahranagat shear system is part of a broader and horizontally more extensive zone than was originally defined, as reflected in part by the northeast-trending lineament system in southern Nevada (E, fig. 3). In the remainder of this paper, we will refer to lineament system E as the Pahranagat lineament system. Extension of this lineament system into Utah for 100 km is distinctive on the Landsat mosaic of the conterminous United States.

Lineament system E, as defined in figure 3, consists of two sub-parallel northeast-trending segments; (1) an 85 km long segment that corresponds to the Kane Springs Wash fault bounding the northern edge of the Meadow Valley Mountains (mm, fig. 3), and (2) a 30 km long segment that represents the zone of faulting in the Pahranagat shear system. The presence of left-lateral shear along the Kane Springs Wash fault (Stewart and Carlson, 1974), as well as its trend parallel to the Pahranagat shear system, suggest the likelihood that the shear movement along the Kane Springs fault is related to the narrow zone of left-lateral faulting in the Pahranagat Range. Another series of northeast-trending left-lateral shear faults mapped just north of

Figure 7 - Map showing (a) the distribution of Cretaceous granodioritic rocks (dark areas), which make up a northeast-trending belt connecting equivalent rocks in the Sierra Nevada and Idaho Batholith (compiled from Carlson and others, 1975 and King and Bleikman, 1974), along the northern border of the Humboldt Structural Zone in Nevada (ruled) and (b) western boundary of Precambrian crystalline rocks in Nevada (stippled) (from Zartman, 1974). Letter symbols defined in fig. 3.

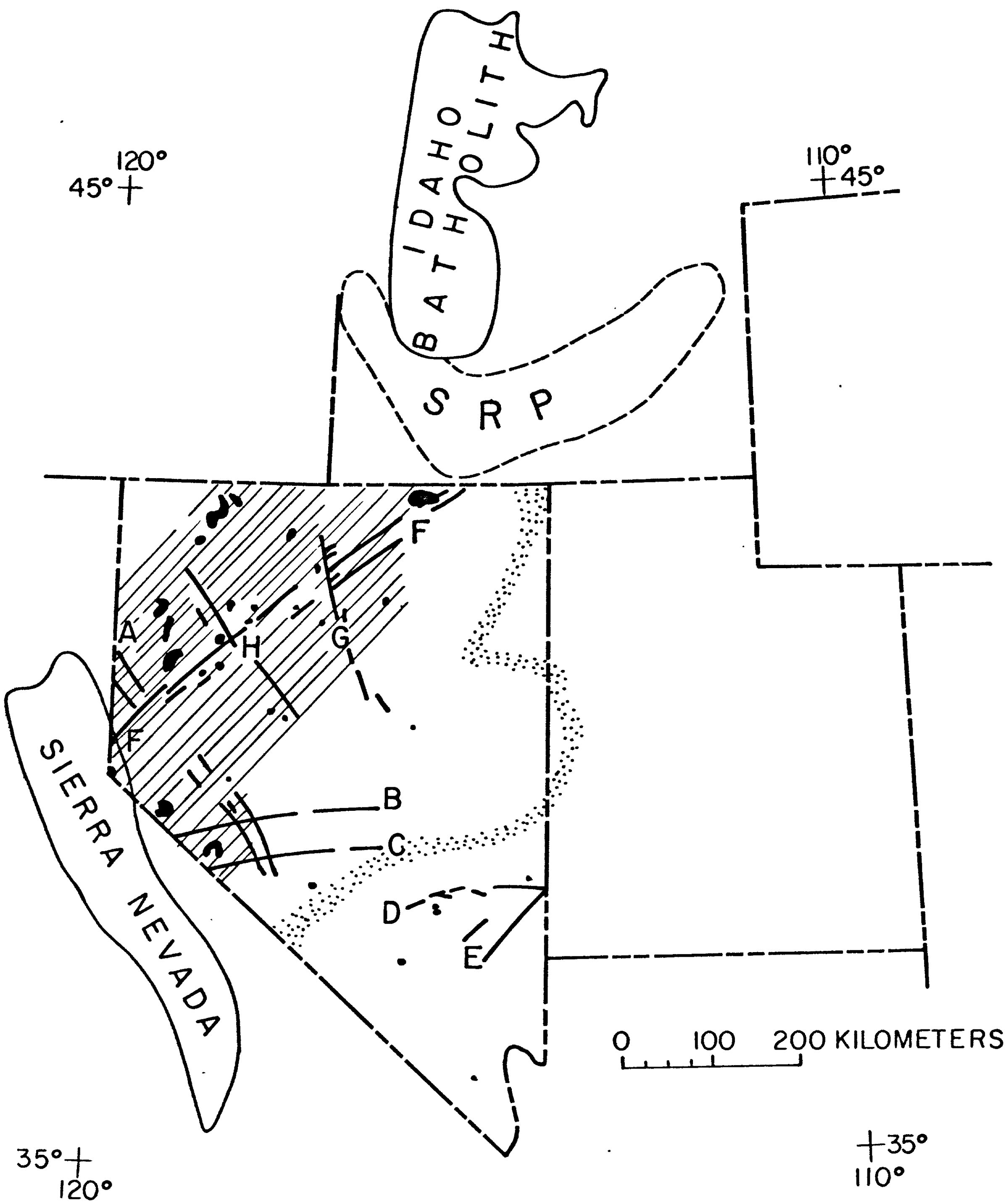
IDAHO BATHOLITH
SRP
SIERRA NEVADA
A
B
C
D
E
F
F
G
H
120°
45°
110°
45°
35°
120°
35°
110°
0 100 200 KILOMETERS

Fig. 7

Lake Meade (1m, fig. 3) is considered part of a broad northeast-trending zone (Anderson, 1973) whose northern boundary is roughly coincident with the Pahranagat shear system. We believe that this broad zone, which the Pahranagat lineament system reflects (E, fig. 3), has regional structural significance. Location of this zone is coincident with the southern end of the Sevier orogenic belt, as defined by Armstrong (1968); Slemmons (1967) has also inferred a relationship between the left-lateral faulting in southern Nevada and the Sevier orogenic belt.

Movement along the Pahranagat shear system appears to be considerably older than the post-Miocene left-lateral faulting evident today. Tschanz and Pampeyan (1970) suggested that it is at least Laramide in age, at which time right-lateral shear was present. They also proposed that the Kane Springs Wash fault may represent an older reactivated structure, noting that indirect evidence suggested right-lateral movement in pre-Miocene time. The Cretaceous and possible late Permian age of the Sevier orogenic belt (Armstrong, 1968) to which the Pahranagat lineament system may be related further documents this minimum age.

The Pahranagat lineament system appears to have influenced the loci of volcanic activity in southeastern Nevada, at least during middle Tertiary time (Stewart and Carlson, 1976). The lineament system lies within a broad 150 km-wide northeast-trending zone of 34-17 m.y. old andesitic lava flows and silicic tuffs. Subsequent eruptions in this area of predominantly silicic tuffs and rhyolitic lava flows and

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intrusive rocks, which range in age from 17-6 m.y., resulted in a northeast-trending 40 km-wide zone of volcanic rocks whose trend, location, and extent coincide with those of the Pahranagat lineament system in Nevada; the Kane Springs Wash caldera lies at the southern end of this zone of volcanics (Stewart and Carlson, 1976). No 43-34 m.y. old volcanic rocks are present along the Pahranagat lineament system, and volcanic rocks younger than 6 m.y. in age are also absent; however, a northeast-trending zone of young basalts coincides with the extension of this lineament system into Utah for 250 km.

In the fault density maps, the Pahranagat lineament system is poorly expressed in the fault density contour maps. The southern end of the lineament system, E, does align with a north-northeast-trending fault concentration (fig. 4e); the west-ward bending of the fault concentration may be due to interaction with the right-lateral shear in the Walker Lane.

The Pahranagat lineament system is expressed on the aeromagnetic map (E, fig. 5a and 5b) by a broad 35 km-wide northeast-trending zone of aeromagnetic highs which extends into Utah for 175 km. The proposed extension into Utah is generally coincident with the intermountain seismic belt (Smith and Sbar, 1974). The zone of aeromagnetic anomalies ends abruptly to the south at an east-trending aeromagnetic low that may be part of the "Quiet Zone" (Stewart and others, 1977); expression of the Pahranagat lineament system also is lost in this same general area.

The Pahranagat lineament system is poorly expressed on the gravity map (E, fig. 6). It does align with the margin of a northeast-trending low at the Nevada-Utah border, and extension of the lineament system northeast parallels the northeast-trending boundary of another area of low gravity. The southern end of the Pahranagat lineament system does not continue beyond the prominent east-trending steep gradient in southern Nevada.

Lineament Systems in Northern Nevada

The three major lineament systems delineated in northern Nevada are referred to as the (1) Midas Trench lineament, (2) Northern Nevada Rift, and (3) Rye Patch lineament (F, G, H, respectively, fig. 3).

Midas Trench Lineament System: The longest lineament system in northern Nevada was first delineated on the Landsat 1 mosaic of Nevada on the basis of aligned, northeast-trending topographic and tonal features (F, fig. 3) (Rowan and Wetlaufer, 1973). The most notable geomorphological features are, from southwest to northeast: (a) prominent northeast-trending fault escarpments and streams in the Pah Rah Range (pr, fig. 3); (b) northeasterly alignment of the West Humboldt and Trinity Ranges (wh and tr, respectively, fig. 3) and of escarpments and streams in the Trinity Range; (c) abrupt northern terminations of the Humboldt, East, and Sonoma Ranges (hr, er, and sr, respectively, fig. 3) and transection of these ranges by deep northeast-oriented canyons; and (d) marked northeastward linearity of Buffalo Mountain (bf, fig. 3), of many streams in individual ranges in the Tuscarora and Independence Mountains (tm and im, fig. 3), and of the escarpment that separates the Owyhee Desert (od, fig. 3) from the mountains to the southeast. Changes in the course of the Humboldt River also suggest a relationship with this lineament system. This feature is referred to as the Midas Trench lineament system because of the prominent northeast-trending structure and topography near Midas, Nevada (mt, fig. 3).

The Midas Trench lineament system traverses approximately 460 km in northern Nevada and appears to extend northeastward along the southeastern margin of the Snake River Plain through Yellowstone Park into Montana. As initially delineated (Rowan and Wetlaufer, 1975), the lineament system was roughly 40-50 km wide. However, the areal distributions of faults and geophysical data indicate that it represents a substantially broader structural zone.

Northeast- and north-northeast-trending faults (figs. 4d and 4e) are more common in northern than in southern Nevada, in sharp contrast to the dominance of northwest-, west-northwest-, and east-trending faults (figs. 4a, 4b, and 4c) in southern Nevada. The combined areal densities of northeast- and north-northeast-trending faults in northern Nevada constitute a northeasterly-oriented zone that is roughly 200 km wide in the southwestern part and tapers northeastward to about 75 km. The Midas Trench lineament system (F, fig. 3) lies within this zone of faulting in northeastern Nevada and marks its northernmost margin in north-central and northwestern Nevada. The width of this zone, comparable to that of the Walker Lane, suggests that the Midas Trench lineament system, as observed on Landsat images, is the morphological expression of a substantially broader feature of major structural importance. The southwestern part of the Midas Trench lineament system is more evident on the north-northeast- than on the northeast-trending fault-density contour map, although several prominent 5-10 km-long northeast-trending faults are present in the Pah Rah Range (pr, fig. 3), and northeast-trending faults bound the northern and southern margins of the Virginia Range (vr, fig. 3) (Bonham, 1969). Shawe (1965) believed that the lineament bounding the Virginia Range to the south can be traced for 162 km.

The Midas Trench lineament system appears to have been a broad zone of left-lateral, strike-slip faulting since mid-Miocene time. Detailed petrologic, magnetic, and structural studies by Zoback and Thompson (1978) at the Sawtooth dike north of Midas indicate that this rhyolitic dike was emplaced during formation of the Northern Nevada Rift (G, fig. 3). The Sawtooth dike and other segments of the Rift further south are offset by northeast-trending left-lateral, strike-slip faults (Mabey, 1966; Robinson, 1970); similar movement is indicated by slickensides on the northeast-trending Crescent fault bounding the Cortez Mountains (cm, fig. 3) on the northwest side (Muffler, 1964). In the Pah Rah Range (pr, fig. 3) south of Pyramid Lake, Bonham (1969) noted left-lateral offsets of stream channels of as much as 15 feet along east-northeast- to northeast-trending faults, and Rose (1969) described left-lateral displacement on similarly oriented faults in the canyon of the Truckee River. Although dip-slip movement is common along north-northeast-trending faults, Slemmons (1967) noted that north-northeast- as well as northeast-trending faults of Quaternary to Pliocene age typically show left-lateral, strike-slip movement. Most of these left-lateral shear faults identified by Slemmons (1967) are located in northern Nevada and are concentrated within the broad Midas Trench system, especially near its intersection with the Northern Nevada Rift.

Volcanic activity has been widespread along the Midas Trench lineament system and in an area to the north (Stewart and Carlson, 1976); bimodal rhyolite and basalt extrusions peaked around 15 m.y. ago, and later basaltic volcanism peaked around 10 m.y. ago (McKee and others, 1971). On the other hand, 34-17 m.y. old volcanic rocks that constitute a prominent arcuate belt extending from southern Utah through southern and southwestern Nevada into northeastern California are notably sparse along the lineament system, except in the Tuscarora and Jarbidge Mountains (tm and jm, respectively, fig. 3), which appear to have been the site of concentrated volcanic activity throughout most of Tertiary time (Albers and Kleinhampl, 1970). Moreover, an east-northeasterly-oriented belt of 43-34 m.y. old volcanic rocks extending across northern Utah and Nevada (Stewart and Carlson, 1976) terminates south of this general region. These spatial distributions suggest that Tertiary volcanic activity along the Midas Trench system was largely restricted to the period of tectonism characterized by left-lateral, strike-slip movement as a result of generally east-west extension of the Great Basin.

The Midas Trench lineament system may have also influenced the distribution of late Cretaceous (105-85 m.y. old) granodioritic and quartz monzonitic plutons. The flexure that connects these rocks in the Sierra Nevada with the petrologically, chemically, and chronologically equivalent rocks of the Idaho Batholith (Moore, 1962; Smith and others, 1971) closely follows the Midas Trench lineament system (fig. 7). Conglomeratic rocks deposited during Pennsylvanian time as the Antler Orogenic Belt developed also trend northeastward across northern Nevada and southern Idaho. However, earlier Paleozoic rocks trend northward in this area (Peterson, 1977). These relationships suggest that the Midas Trench system was periodically rather than continuously active.

Several lines of geophysical evidence support the concept that the Midas Trench lineament system is the surface manifestation of a major crustal feature. The generalized simple Bouguer gravity map (F, fig. 6) shows a change in the trends and magnitudes of anomalies in the vicinity of the Midas Trench lineament system. Central and southern Nevada are characterized by generally northerly-oriented gravity anomalies and the previously mentioned prominent east-trending gradient south of the Timpahute lineament system (D, fig. 6). In northwestern Nevada and adjacent areas, the gravity anomalies trend northeast and are generally higher than in central Nevada. The transition between these two areas is broad, similar to the 200 km-wide zone of concentrated northeast- and north-northeast-trending faults (figs. 4d and 4e) and is complicated by the presence of several broad crudely blocky anomalies. North and south of the intersection of the Midas Trench and Rye Patch systems (F and H, respectively, fig. 6), the lineament systems appear to partially bound the gravity anomalies. Because broad anomalies such as these reflect crustal variations and not topography (Eaton and others, in press), the lineaments may outline major crustal blocks.

Aeromagnetic map patterns in northern Nevada provide subtle indications of the presence of the Midas Trench lineament system (F, fig. 5a). These include northeast-trending anomalies in the southwestern part of the system, mainly associated with Cenozoic volcanic rocks (Stewart and others, 1977), termination and interruption of the north-northwest-to-north-northeast anomalies denoting dominantly granitic ranges in the central part (Mabey and others, in press), and a broad, northeast-oriented transition zone in northeastern Nevada where the Cenozoic volcanic rocks of the Owyhee Desert (od, fig. 3) contrast with dominantly intrusive and sedimentary rocks in the mountains to the southeast. More conspicuous patterns are present further to the northeast where aeromagnetic highs associated with the Snake River Plain and Yellowstone Park volcanic rocks are clearly aligned in the northeasterly direction (fig. 5b). Although most of this belt, termed the Humboldt Zone by Mabey and others (in press), consists dominantly of Cenozoic basaltic rocks, Precambrian rocks near the southern border of Idaho account for a prominent positive anomaly (Eaton and others, 1975).

Northeast of Yellowstone Park, broad northeasterly-oriented highs and northeast-trending surface faulting suggest northeastward extension of this crustal zone into Montana. These faults, which include the Fromberg, Weldon, and Brockton zones, form the southeastern boundary of the projected magnetic anomaly (fig. 5b). Eaton and others (1975, p. 795) pointed out that these faults constitute a "major boundary at which regional northwesterly magnetic trends on the southeast are separated from northeasterly magnetic trends on the northwest". Regional stratigraphic data indicate recurrent movement in basement faults in Paleozoic, Mesozoic, and Cenozoic time (Zietz and others, 1971), and displacement of Pleistocene deposits along the Brockton faults (Colton, 1963). Eaton and others (1975) concluded that progression of volcanic activity northeastward along the Snake River Plain to Yellowstone Park was guided by these Precambrian basement structures. If this is the case, Precambrian structures probably also controlled the preferential concentration of northeast- and north-northeast-trending faults and magmatic invasion along the Midas Trench lineament system southward into north-central Nevada.

Heat-flow measurements in the western United States have permitted delineation of a unique, extensive, northeast-trending area with heat flow greater than 2.5 heat flow units (HFU), the Battle Mountain High (fig. 8) (Lachenbruch and Sass, 1977; Lachenbruch, in press). This feature extends from Steamboat Springs, Nevada to the southern margin of the Snake River Plain; it probably extends all the way to the Yellowstone Park geothermal field, considering the groundwater conditions in the intervening area (Lachenbruch and Sass, 1977). In central Nevada, the 150-200 km-wide Battle Mountain High not only coincides

Figure 8 - Generalized map of heat flow and physiographic provinces in the western United States (after Lachenbruch and Sass, 1977). Abbreviations are BMH for Battle Mountain High, SRP for eastern and central Snake River Plain, IB for Idaho Batholith, Y for Yellowstone geothermal area, RGR for Rio Grande Rift, EL for Eureka Low, and LV for Long Valley volcanic center.

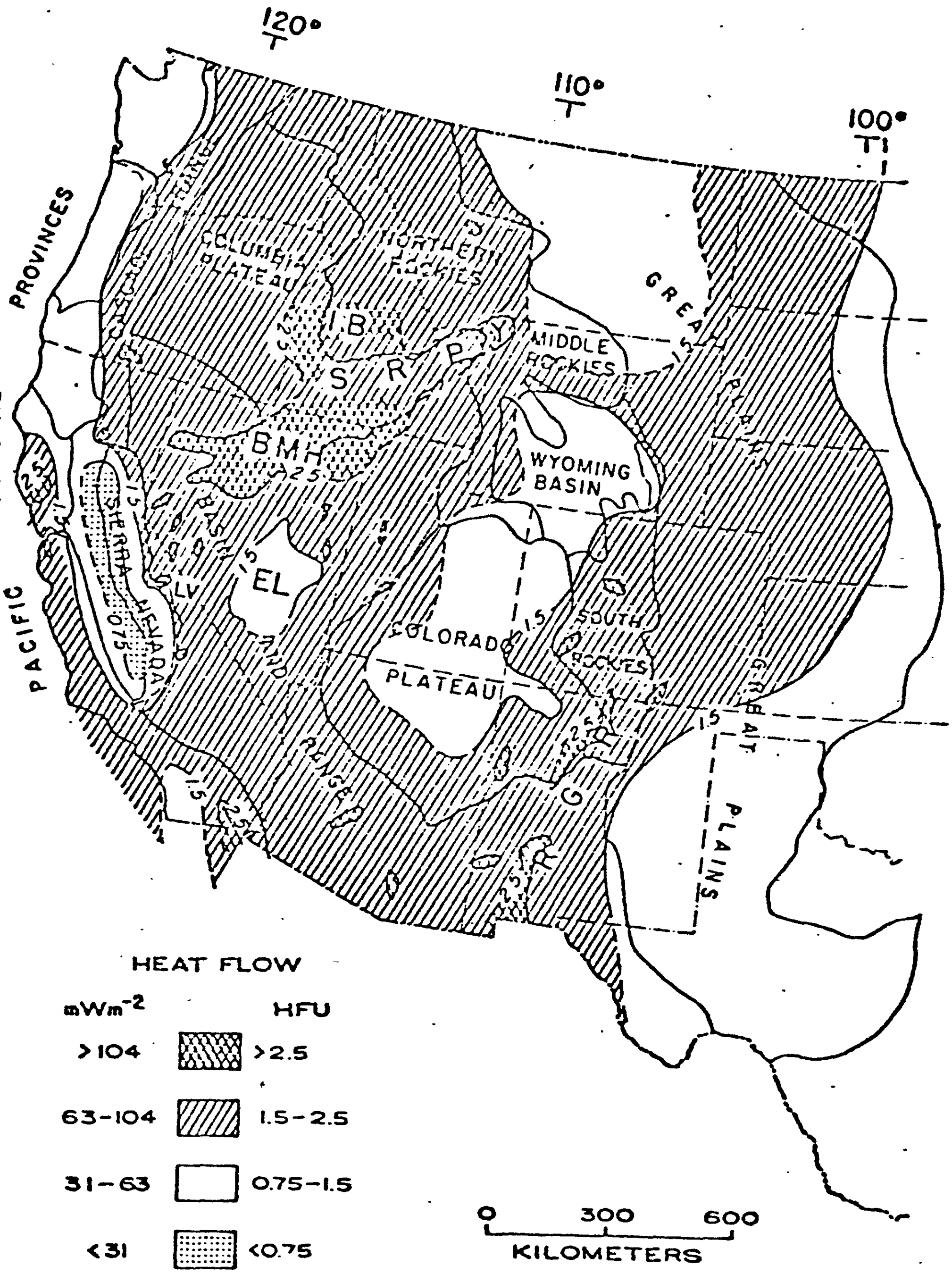
120°
110°
100°
COASTAL
PROVINCES
PACIFIC
COLUMBIA PLATEAU
NORTHERN ROCKIES
S R P
MIDDLE ROCKIES
BMH
WYOMING BASIN
SIERRA NEVADA
EL
LV
COLORADO PLATEAU
SOUTH ROCKIES
GREAT PLAINS
HEAT FLOW
mWm-2
HFU
>104
>2.5
63-104
1.5-2.5
31-63
0.75-1.5
<31
<0.75
0
300
600
KILOMETERS

Figure 8

along its length with the Midas Trench lineament system, but also generally coincides in breadth with the belt of anomalously high density of northeast- and north-northeast-trending faults (figs. 4d and 4e, respectively), and with the northeast-trending transition zone noted in the simple Bouguer gravity map (fig. 6). Apparent disruption of the Battle Mountain High in west-central Nevada may be due to inter-basin hydrologic conditions similar to those described by Lachenbruch and Sass (1978) for the Eureka Low.

Analysis of seismic data (Koizumi and others, 1973; Hill and Pakiser, 1967) indicate a major structural discontinuity extending from Lovelock to Mountain City (lk and mc, fig. 3). Koizumi and others (1973) interpreted the discontinuity as a northeast-trending high velocity lithospheric plate having a dip of 60°-70°SE and a slab length of at least 150 km. Additional seismic data interpreted by Proedhl (1970) show a crustal velocity contour map in which the two-second contour line corresponds with the location and orientation of the Midas Trench lineament zone.

<u>Northern Nevada Rift</u>: The lineament system (G, fig. 3) denoting the Northern Nevada Rift is conspicuous in the Landsat image mosaic owing to north-northwest alignment of a series of escarpments and tonal features transecting the north-northeasterly-oriented ranges of north-central Nevada for approximately 200 km (Rowan and Wetlaufer, 1975). This feature was initially delineated in Nevada on the basis of the presence of a distinct zone of north-northwest-aligned positive magnetic anomalies (G, fig. 5a) (Mabey, 1966; Robinson, 1970).

The Northern Nevada Rift is poorly expressed in the north-northwest-trending fault density map (fig. 4f). The concentrations of north-northwest-trending faults in northern Nevada appear to have been more influenced by the northern portion of the broad Midas Trench lineament system. However, it is probably significant that the Northern Nevada Rift marks the western limit of almost all north-northwest-trending fault concentrations. In southeastern Nevada, the only major occurrence of north-northwest-trending faults aligns with, but lies just northwest of, the only other northeast-trending lineament system noted in this report, the Pahranagat lineament system (E, fig. 3). Concentrations of east-to-east-northeast- and northeast-trending faults (figs. 4c and 4d, respectively) align locally with the Northern Nevada Rift; these concentrations must also be, at least in part, related to the Midas Trench system because they are generally localized near the intersection of the Northern Nevada Rift and the Midas Trench system.

The aligned aeromagnetic highs along the Northern Nevada Rift (G, fig. 5a and 5b) are attributed to a linear mafic dike swarm that was the source of a narrow belt of basaltic volcanic rocks (Mabey, 1966). These dikes, along with rhyolitic, dacitic, and andesitic rocks, were emplaced between 13.8 and 16.5 m.y. ago along a zone of structural weakness termed the Northern Nevada Rift (Zoback and Thompson, 1978). The Northern Nevada Rift is expressed in the simple Bouguer gravity map (G, fig. 6) near its intersection with the Midas Trench system as a north-northwest-trending gradient separating a broad low in the east-from intermediate gravity to the west. Southward extension of this system into central Nevada is coincident with the axis of bilateral symmetry noted by Eaton and others (in press). However, the Rift appears to be confined to Nevada instead of being part of a longer feature such as the Oregon-Nevada lineament proposed by Stewart and others (1975).

Rye Patch Lineament System: The three lineaments making up the Rye Patch lineament system (H, fig. 3) are parallel to and lie about 100 km northeast of the Walker Lane. The Humboldt, West Humboldt, and Antelope Ranges (hr, wh, and ar, respectively, fig. 3) terminate against the Rye Patch system, and others, including the Stillwater and Clan Alpine Ranges (sl and cr, respectively, fig. 3), appear to be offset by it. The lineaments are distinctive largely because of juxtaposition of rocks with contrasting albedos; northwesterly-oriented topographic features tend to be subdued rather than enhanced by the similarly oriented solar aximuth (approximately N45°W).

Along most of the northern lineament, Jura-Triassic metasedimentary rocks are present in the northeast (ar, fig. 3), whereas, relatively bright Tertiary silicic ash flow tuffs dominate the area to the southwest (Stewart and Carlson, 1974). At its southern end, this lineament separates Triassic metasedimentary and metavolcanic rocks in the Humboldt Range (hr, fig. 3) from Jura-Triassic metasedimentary rocks in the West Humboldt Range (wh, fig. 3) to the southwest; bright Tertiary tuffaceous sedimentary rocks occupy the topographic low occupied by the lineament.

Along the southern lineament of the Rye Patch system, Jura-Triassic metasedimentary and Triassic metavolcanic rocks in the north are juxtaposed with Tertiary volcanic and Jurassic gabbroic rocks in the Stillwater Range (sr, fig. 3). The distribution of the gabbroic rocks is particularly important because such rocks are rare in Nevada (Stewart and Carlson, 1974), and here they are present as scattered masses southwest of the lineament in the West Humboldt, Stillwater, and Clan Alpine Range (wh, sl, and cr, respectively, fig. 3); they are absent northeast of the lineament. Additional marked lithologic contrasts occur across the segment in the Desatoya and Shoshone Mountains (dm and sm, respectively, fig. 3), where middle and late Paleozoic sedimentary rocks occur in the northeast and Tertiary silicic ash-flow tuffs underlie large areas to the southwest.

Most of the areas of lithologic contrast along the southeastern lineament are disrupted by northwesterly-trending faults. However, the fault densities, as portrayed by the State geologic map (Stewart and Carlson, 1974), are not particularly high in these areas, so that only scattered intermediate concentrations of northeast-, north-northeast-, and north-northwest-trending faults are present along this lineament (figs. 4d, 4e, and 4f, respectively). Most of the concentrations are oriented northwesterly. The paucity of faults of any orientation along the northwestern segments of the system is probably due to the general lack of detailed mapping in that area.

Sense of movement along the Rye Patch lineament system is not known. However, its position near the northeastern boundary of the broad zone defining the Walker Lane and its trend parallel to the Walker Lane suggests possible right-lateral, strike-slip movement. The age of the Rye Patch lineament system is also difficult to evaluate, but it is coincident with a Precambrian trend proposed by Roberts (1966).

In the simple Bouguer gravity map, the southern part of the Rye Patch lineament system (H, fig. 6) closely parallels a northwest-trending 170 mgal contour line which, in part, defines the previously described blockiness of the gravity pattern in this part of northern Nevada. The northern portion of the lineament system more or less marks the southwestern limit of a local gravity high (-170 to -130 mgal) whose southeastern border is defined by the Midas Trench lineament system.

The southeastern lineament of the Rye Patch system (H, figs. 5a and 5b) marks a regional change in the aeromagnetic map pattern. To the southwest, the pattern is characterized by high-frequency highs and lows that trend northwesterly; to the northeast, the anomalies are typically low-frequency features with northerly trends. The northern segments of the system lie within a northwest-trending 2300-2400 gamma low (H, fig. 5a).

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Summary and Discussion of Lineament Systems

The areal distribution of faults with respect to azimuth along with geophysical data is strong evidence that most of the major lineament systems are valid structural features (Table 1), and that they are expressions of substantially broader crustal zones that crosscut the northerly-trending topographic grain of the Great Basin.

Southern Nevada is dominated by three broad zones (fig. 9): (1) the Walker Lane, which is expressed by a 175 km-wide belt of northwesterly-oriented faults and by aeromagnetic and gravity anomalies of similar orientation and width (A, fig. 9); (2) a 150 km-wide zone which includes the three east-trending lineament systems and which is characterized by east-to-east-northeast-trending faults and by a prominent easterly grain in the aeromagnetic data (B, C, and D, fig. 9); and (3) a 125 km-wide zone of northeast-trending faults which includes the Pahranagat shear system and similarly oriented faults in the Lake Meade, Nevada area (E, fig. 9).

Northern Nevada is dominated by a 75-200 km-wide northeasterly-oriented belt of northeasterly-trending faults which includes the Midas Trench lineament system (F, fig. 9); northwesterly and east-to-east-northeasterly-trending faults are subordinate. The broad configuration of the Midas Trench system is also marked by northeast-trending gravity anomalies, which contrast with the more northerly trends farther south, by the presence of the northeasterly-oriented Battle Mountain Heat Flow High, by discontinuities of northerly-oriented aeromagnetic anomalies, and locally by the presence of northeast-trending aeromagnetic anomalies (table 1). Alignment of the Midas Trench system with the Snake River Plain, with northeast-trending aeromagnetic anomalies in Precambrian crystalline rocks, and with northeast-trending faults in Montata suggest extension of this feature 400 km northeastward from Nevada.

Intersection of the Rye Patch lineament system and the Northern Nevada Rift (H and G, respectively, fig. 3) with the Midas Trench lineament system corresponds with a blockiness in the fault concentration patterns and in the geophysical data in northern Nevada. The Rye Patch system appears to bound some of the blocky northeast-trending gravity anomalies in the vicinity of the Midas Trench system. Furthermore, this lineament system marks a boundary between northwesterly-oriented, high-frequency aeromagnetic anomalies to the southwest and northerly-trending, low-frequency anomalies to the northeast. On a more local scale, northwesterly-aligned aeromagnetic anomalies are either coincident with or parallel to the lineaments making up the Rye Patch system. The Northern Nevada Rift (G, fig. 9) is narrowly defined by north-northwest-trending faults and denotes a zone on most of the other fault density maps which disrupts faulting along the Midas Trench lineament system. A series of prominant aeromagnetic highs along the Northern Nevada Rift is associated with the presence of basaltic dikes and volcanic rocks.

Field relationships suggest that these broad transverse zones have been the sites of strike-slip faulting at least since about 17 m.y. ago when the basins and ranges began forming (Stewart, 1971) (table 1).

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TABLE 1

CHARACTERISTICS OF ZONES REPRESENTED BY MAJOR LINEAMENT SYSTEMS IN NEV

LINEAMENT SYSTEM NAME	LETTER	TREND	LENGTH (APPROX)	WIDTH (APPROX)	EXPRESSION IN LANDSAT IMAGES	EXPRESSION ON FAULT DENSITY MAP (FIG) PRIMARY: ___	OTHER GEOLOGIC EVIDENCE	AEROMAGNETIC
Walker Lane	A	NW	600 km	175 km	Disruption of basin-range topography	NW (4a) E-ENE (4c) WNW (4b)	Stratigraphic displacement, mapped faults, recent faulting, concentration of 34-6 m.y. old & younger volcanic rocks	Broad NW-trending arcuate belt of high-frequency anomalies terminat at "Quiet Zone"
Pancake Range	B	E-ENE	250 km	150 km	Disruption & termination of ranges & alignment of tonal features	E-ENE (4c) NW (4a)	Stratigraphic displacement, contrasting structural patterns, caldera boundary, alignment of 34-6 m.y. old volcanic rocks	E-trending grain in broad NW-tren arcuate belt of Walker Lane
Warm Springs	C	E-ENE	400 km		Disruption & termination of range & alignment of escarpment & tonal anomalies	NW (4a) E-ENE (4c)	Structural discontinuities & apparent stratigraphic displacement; concentration of 34-6 m.y. old volcanic rocks	Pronounced E-trending grain in br NW-trending arcuate belt of Walke Lane
Timpahute	D	E-ENE	150 km		Disruption of N-trending ranges & alignment of E-trending ridges	WNW (4b) NW (4a) E-ENE (4c)	E-W alignment of intrusive bodies & of 34-6 m.y. old volcanic rocks; stratigraphic discontinuities & contrasting structural patterns across lineaments	Alignment with E-trending lows
Pahranagat	E	NE	125 km	125 km	Steep escarpment & drainage	NE (4d) NNE (4e) NNW (4f) NW (4a) N (4g)	Well-documented left-lateral strike-slip faults & associated stratigraphic discontinuities; coincident with belt of 34-6 m.y. old volcanic rocks & with <6 m.y. volcanic rocks along NE extension	NE-oriented belt of anomalies
Midas Trench	F	NE	1000 km	75-200 km	Termination & disruption of ranges; alignment of ranges, canyons, streams escarpments & tonal features	NE (4d) NNE (4e) N (4g) E-ENE (4c) NNW (4f)	Left-lateral strike-slip faults including displacement along Northern Nevada Rift; alignment of 17-6 m.y. and ≤6 m.y. old volcanic rocks & of volcanic centers; flexure of 105-85 m.y. granodioritic plutons along lineament system; alignment with Snake River Plains downwarp & with old reactivated NE-trending faults in Montana	Discontinuities & terminations of N-trending anomalies; alignment of NE-trending anomalies
Northern Nevada Rift	G	NNW	200 km	20 km	Alignment of escarpments & tonal anomalies; disruption of NE-trending ranges	NE (4d) NNW (4f) E-ENE (4c) NNE (4e)	Alignment of Tertiary basaltic, rhyolite, dacitic, & andositic dikes	Prominent NNW-trending highs
Rye Patch	H	NW	250 km	Suggested NE boundary of Walker Lane	Alignment of tonal anomalies, disruption & termination of ranges	NE (4d) NNE (4e)	Juxtaposition of greatly different age rocks & contrasting structural patterns across lineament; alignment of gabbroic rocks along southern lineament	Coincident with/parallel to NW-tr anomalies; boundary between NW-tr high-frequency anomalies to SW & N trending low-frequency anomalies

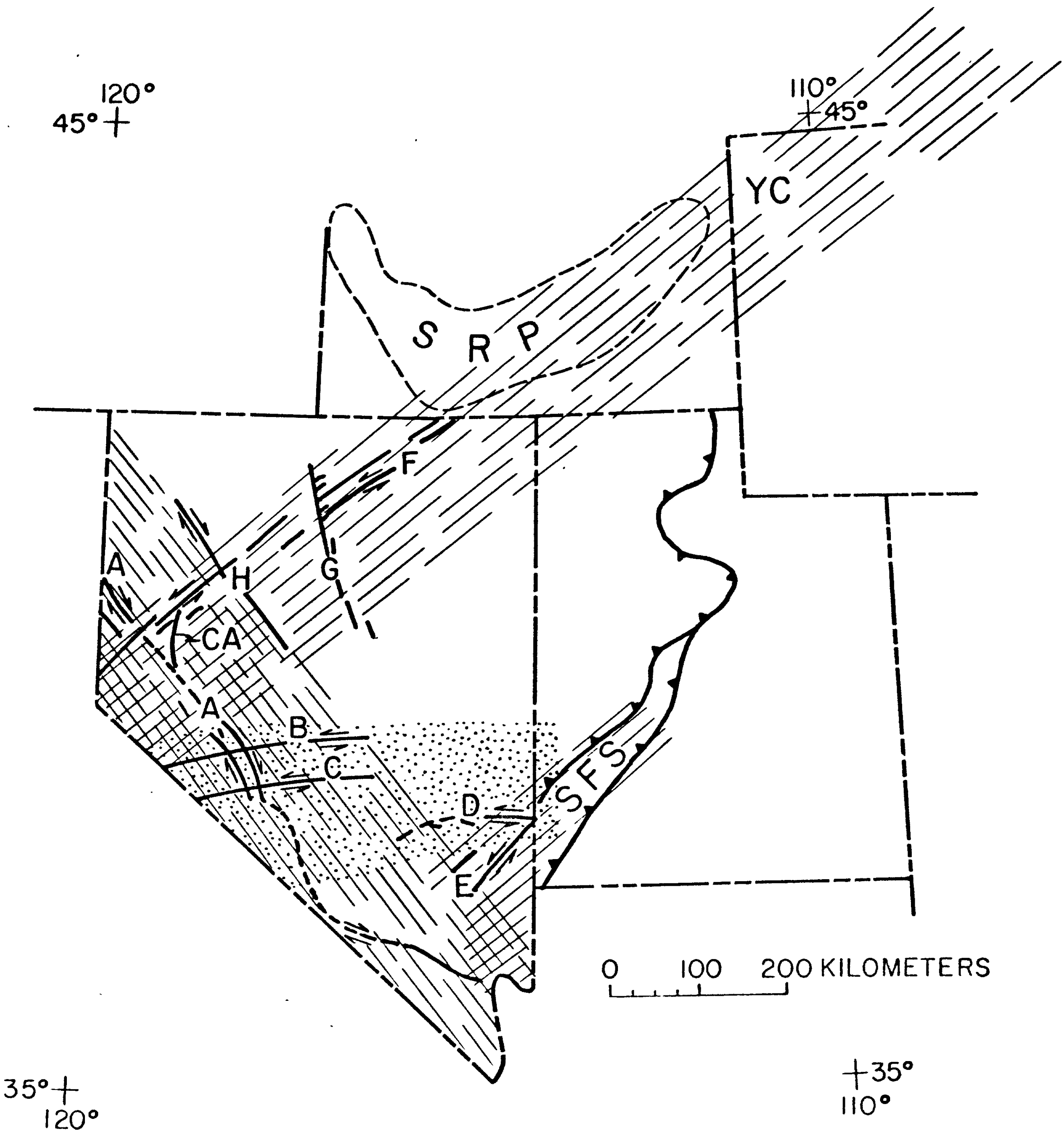
32a

TABLE 1

TERISTICS OF ZONES REPRESENTED BY MAJOR LINEAMENT SYSTEMS IN NEVADA

LOGIC EVIDENCE	AEROMAGNETIC	GRAVITY	HEAT FLOW	EARLIEST APPARENT AGE	SENSE OF CENOZOIC MOVEMENT	ORE DEPOSIT ASSOCIATION
t, mapped faults, recent f 34-6 m.y. old & younger	Broad NW-trending arcuate belt of high-frequency anomalies terminating at "Quiet Zone"	Broad NW-trending belt of moderately low gravity	Scattered heat flow high in northern part	Precambrian	Right-lateral strike-slip	Broad NW-trending belt terminating at "Quiet Zone"; concentration of mercury, antimony & iron
t, contrasting structural y, alignment of 34-6 m.y.	E-trending grain in broad NW-trending arcuate belt of Walker Lane	Subtle easterly deflection of contours	None evident	Precambrian	Left-lateral strike-slip	E-trending grain in broad NW Walker Lane belt; alignment of antimony deposits
s & apparent stratigraphic on of 34-6 m.y. old volcanic	Pronounced E-trending grain in broad NW-trending arcuate belt of Walker Lane	None evident	None evident	Precambrian	Left-lateral strike-slip	E-trending grain in broad NW trending Walker Lane belt
o bodies & of 34-6 m.y. old phic discontinuities & tterns across lineaments	Alignment with E-trending lows	Parallels very steep E-trending gradient to the south	None evident	Precambrian	Left-lateral strike-slip	Near E-trending Pioche belt
ral strike-slip faults & discontinuities; coincident d volcanic rocks & with ong NE extension	NE-oriented belt of anomalies	Little expression but parallels anomalies in Utah	None evident	At least Laramide but probably Precambrian	Left-lateral strike-slip	Slight
faults including displacement t; alignment of 17-6 m.y. rocks & of volcanic centers; anodioritic plutons along nt with Snake River Plains ivated NE-trending faults in	Discontinuities & terminations of N-trending anomalies; alignment of NE-trending anomalies	Broad NE-trending anomalies & higher gravity than to the south	NE-trending Battle Mountain high	Precambrian	Left-lateral strike-slip	Broad NE-trending belt; concentration of mercury & antimony deposits
altic, rhyolite, dacitic, &	Prominent NNW-trending highs	Coincident with NNW-trending gradient & aligns with axis of bilateral symmetry S	None evident	Miocene, but perhaps substantially older	Dip-slip	Low areal density
ifferent age rocks & terns across lineament; s along southern lineament	Coincident with/parallel to NW-trending anomalies; boundary between NW-trending high-frequency anomalies to SW & N-trending low-frequency anomalies to NE	Bounds NE-trending anomalies of Midas Trench system	None evident	Precambrian(?)	Right-lateral strike-slip(?)	Coincident with high at intersection with Midas Trench & NW-trending grain to NW of intersection

Figure 9 - Sketch map showing broad zones represented by major lineament systems; northeast-oriented ruled lines represent northeasterly-trending zones; northwest-oriented rules lines represent north-westerly-trending zones; and stippled pattern represents easterly-trending zones. Letters A-H indicate lineament systems shown in fig. 3. Arrows indicate post-mid-Miocene sense of movement. CA, Churchill Arc (Shawe, 1965); YC, Yellowstone caldera (Eaton and others, 1975); SFS, Sevier fault system (Burchfiel and Davis, 1972); SRP, Snake River Plain.



120°
45°
110°
45°
YC
S R P
F
G
H
A
CA
A
B
C
D
E
SFS
0 100 200 KILOMETERS
35°
120°
35°
110°

Fig. 9

Northwest-trending zones are dominated by right-lateral, strike-slip movement whereas northeast- and east-to-east-northeast-trending zones are characterized by left-lateral strike-slip. Deformation within these broad zones apparently occurred in response to two different regional stress conditions, which respectively resulted in extension in an east-northeasterly direction, followed by extension in a northwesterly direction.

Rifting of the Great Basin was initiated when back-arc spreading caused extension in a generally east-northeasterly direction (Zoback and Thompson, 1978; Eaton and others, in press); the Northern Nevada Rift (fig. 10a) and Columbia River Plateau basalt flows and related dikes formed during this period, judged to be about 14-17 m.y. ago (Zoback and Thompson, 1978). Strike-slip movement may have resulted under these conditions, with right-lateral displacement along northwest-trending fault zones, such as the Walker Lane, and left-lateral movement along north-northeast-trending faults, such as those concentrated within the Midas Trench system (figs. 4e and 10a). Although most of the major right-lateral displacement apparently took place along the Walker Lane prior to this time (Albers, 1967) disruption of the basin-range topography and the occurrence of historic earthquakes along these zones clearly indicate post-mid-Miocene movement (table 1).

Relationships at the Sawtooth dike and elsewhere along the Northern Nevada Rift indicate northeast-trending, left-lateral faulting between 14 and 6 m.y. ago, as the extension direction changed to N65°W and S65°E (Zoback and Thompson, 1978) (fig. 10b and table 1). This direction of

Figure 10 - Schematic diagram showing extension directions and orientation and sense of movement of faults during periods (a) 17-14 m.y. ago, and (b) 14-6 m.y. ago based on evidence along the Northern Nevada Rift (NNR) (after Zoback and Thompson, 1978).

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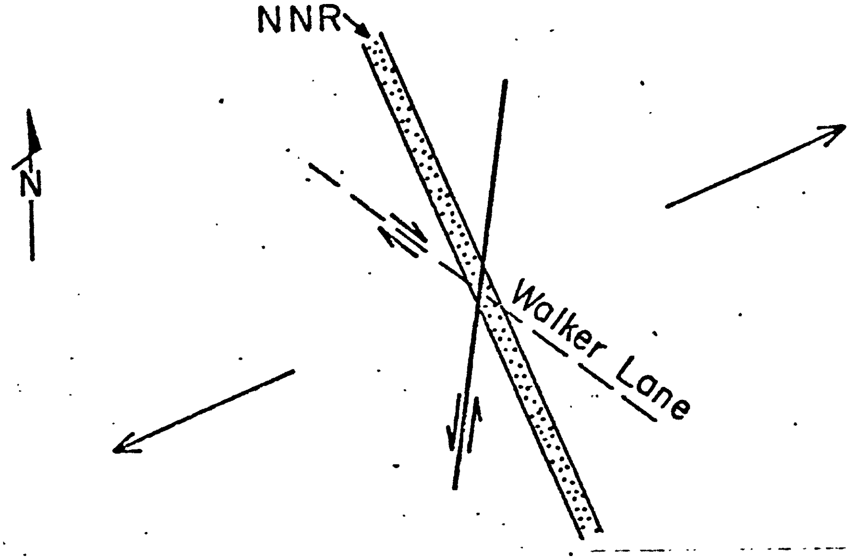
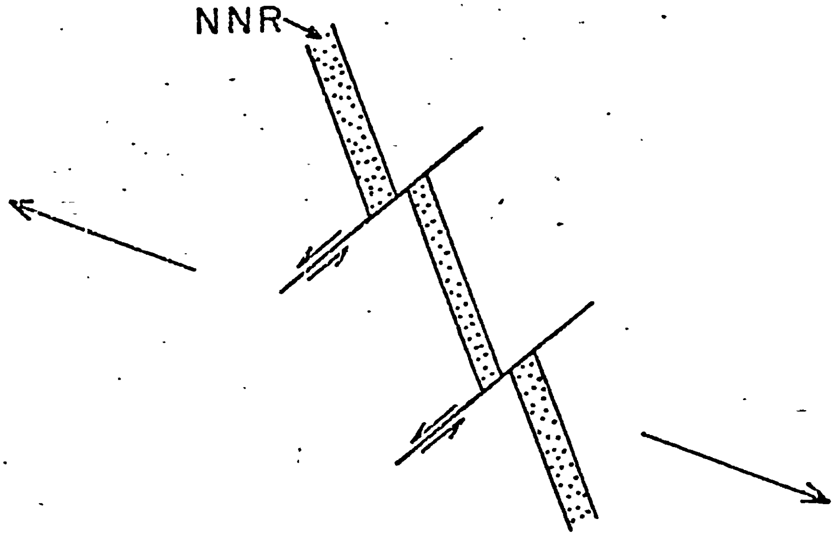


(a) 17-14 M.Y. ago



(b) 14-6 M.Y. ago

Fig. 10

extension, which persists to the present, is consistent with both the northeast orientation and sinistral sense of movement in northern and southeastern Nevada (fig. 10b). It is important to note that volcanism was prevalent along the Midas Trench and Pahranagat lineament systems during the 17-6 m.y. period and has continued during Plio-Pleistocene time (Stewart and Carlson, 1976).

These post-mid-Miocene regional stress conditions do not readily explain the prominence of east-trending, left-lateral, strike-slip zones in southern Nevada. They may have been active prior to this time in response to generally east-northeast-to-west-southwest compression as the Farallon plate descended into the trench along the western continental margin (Atwater, 1970). Reactivation of continued activity during post-mid-Miocene time may have been along secondary shears at the boundary between the rapidly spreading southern Nevada area and the less active area to the south (Eaton and others, in press).

Interaction among the major lineament systems characterized by transcurrent movement suggests a conjugate relationship, as proposed by Shawe (1965), at least during the latest deformation. The strongest evidence for a conjugate shear system is the fact that lineament systems typically intersect without deflection of either feature, suggesting mutually compensating movements. Additional support for a conjugate shear interaction between the Walker Lane and the east-trending systems are: (1) the discontinuous nature of the right-lateral strike-slip faulting comprising the Walker Lane; (2) the tendency for concentrations of east-to-east-northeast-oriented faults to fill the central gap in the northwest-trending fault patterns (figs. 4c and 4a, respectively); (3) the northwesterly alignment of these fault density highs within the Walker Lane zone which mimics the trend of the major northwest fault zone; and (4) the aeromagnetic map pattern which is segmented and which has a distinct easterly as well as northwesterly grain within the Walker Lane zone (fig. 5a).

Interaction of the Walker Lane and the Pahranagat lineament system is poorly understood. Tschanz and Pampeyan (1970) noted that the latter is at least Laramide in age, at which time right-lateral shear, as opposed to the present left-lateral shear, may have been dominant. Anderson (1973) suggested that the Walker Lane offsets the southwestward extension of the Pahranagat shear system, but we feel that the interaction is more complex.

The intersection of the Walker Lane and the Midas Trench system is marked by a narrow arcuate belt (CA, fig. 9) of historically active faults. North-northwest-striking faults are dominant in the southern part of the arcuate belt in the proximity of the Walker Lane, whereas north-northeast-trending faults are dominant in the northern part of the belt near the Midas Trench system (Slemmons, 1967). The sense of displacement changes from dominantly right-lateral strike-slip to dip-slip concommittantly with the change in orientation from north-northwest to north-northeast (Shawe, 1965). This arcuate belt is referred to as the Churchill Arc by Shawe (1965). These spatial relationships, along with the changes in orientation and sense of displacement, suggest that the historical earthquake-associated faults have been influenced by movements within the Midas Trench system, as well as within the Walker Lane.

Intersection of the Midas Trench with the Northern Nevada Rift is the exception with respect to the lack of deflection of lineament systems at their intersections; the dikes marking the rift are clearly displaced left-laterally by northeast-trending faults of the Midas Trench system. It is interesting that north-northeast-trending faults formed earlier in the Midas Trench are interrupted by a broad fault density low along the rift, perhaps suggesting that these faults were once concentrated along a continuous belt and then displaced by rifting (fig. 4e). The Northern Nevada Rift is also the only lineament system which can be very narrowly defined in breadth, as opposed to the proposed broad structural zones, which include the other seven lineament systems.

All the major lineament systems except the Northern Nevada Rift appear to have been established as important crustal features prior to the post-mid-Miocene extensional deformation (table 1). Stratigraphic evidence suggests a Precambrian age for the Walker Lane (Stewart and others, 1968), and the Rye Patch lineament system may be temporally, as well as spatially, related to this major zone of transcurrent faulting. That the Midas Trench system was established at least by Cretaceous time is indicated by the distribution of 85-105 m.y. granodioritic rocks along the system in northern Nevada. However, a Precambrian ancestry is implied for this system based on its alignment with major basement discontinuities in Montana that, judging from northeast-trending faults, have been active since Paleozoic time. Field relationships indicate that the Pahranagat lineament system may have been active at least as early as Laramide time (Tschanz and Pampeyan, 1970; Anderson, 1973), and the prevalence of northeast trends in Precambrian rocks in adjacent regions to the east may suggest a Precambrian origin. The east-trending lineament systems appear to be controlled by well-documented Precambrian structures extending into southern Nevada from Utah (Rowan and Wetlaufer, 1975; Ekren and others, 1976; Stewart and others, 1977).

The diverse geological and geophysical evidence indicates that the seven major lineament systems characterized by transcurrent movement (A, B, C, D, E, F, and H, fig. 3) are the post-mid-Miocene surface manifestations of old, perhaps Precambrian, crustal zones. During the latest deformation (14-6 m.y.), these systems appear to have acted as elements of a conjugate system characterized by right-lateral strike-slip along northwest-trending zones and left-lateral strike-slip in east-to-east-northeast- and northeast-trending systems (fig. 9). The sense of movement along some of the systems during earlier deformations may have been significantly different than the conjugate pattern documented for mid-Miocene and post-mid-Miocene times. For example, right-lateral strike-slip is suspected during Mesozoic time within the Pahranagat shear, and the displacement of 85-105 m.y. granodioritic plutons between the Sierra Nevada and the Idaho Batholith may imply similar movement along the Midas Trench system. On the other hand, the Walker Lane appears to have been dominated by right-lateral strike-slip movement, at least since Mesozoic time (Albers, 1967). It is doubtful that tectonism was continuous within these zones throughout the long periods of time involved. Episodic movement in response to changes in the regional stress field seem more likely. Such a pattern of movement would explain the presence of broad crustal zones that are now recognized by their latest morphological expressions.

OCCURRENCE OF ORE DISTRICTS

Prevailing theories for localization of ore in the western United States include alignment along major tectonic features and at their intersections, association with igneous rocks, whose distribution is, at least in part, structurally controlled, and the existence of metal provinces in the mantle (Jerome and Cook, 1967; Noble, 1970, 1974). We propose that localization of many precious and base-metal ore districts in Nevada was influenced by old, periodically reactivated, broad transverse shear zones (fig. 9) which are defined by six of the eight lineament systems in figure 3. Guild (1978) points out that lineaments which have influenced the distribution of ore deposits are indeed typically old zones which have been periodically reactivated. Although the value of lineaments as guides to ore deposits has been criticized (Gilluly, 1977), we feel that correlation between ore deposit distribution and some lineaments should not be unexpected, especially if geologic and geophysical data suggest that such lineaments represent valid structural features.

Analysis

In order to evaluate patterns of ore distribution in Nevada, occurrences of the following individual metals were examined: gold, silver, lead, zinc, copper, molybdenum, mercury, antimony, iron, manganese, titanium, and uranium (fig. 11). The most obvious feature of the metal-distribution maps is the consistent paucity of metals in the very southeastern, northwestern, and northeastern parts of Nevada. The metal-poor zone in southeastern Nevada has been designated the

Figure 11 - Distributions of individual metal districts in Nevada (Beal, 1962; Horton, 1962; Horton and others, 1962a, 1962b, 1962c, 1962d, 1962e; Lawrence, 1961, 1962; Schilling, 1962a, 1962b, 1963).

Fig. 11 a-d

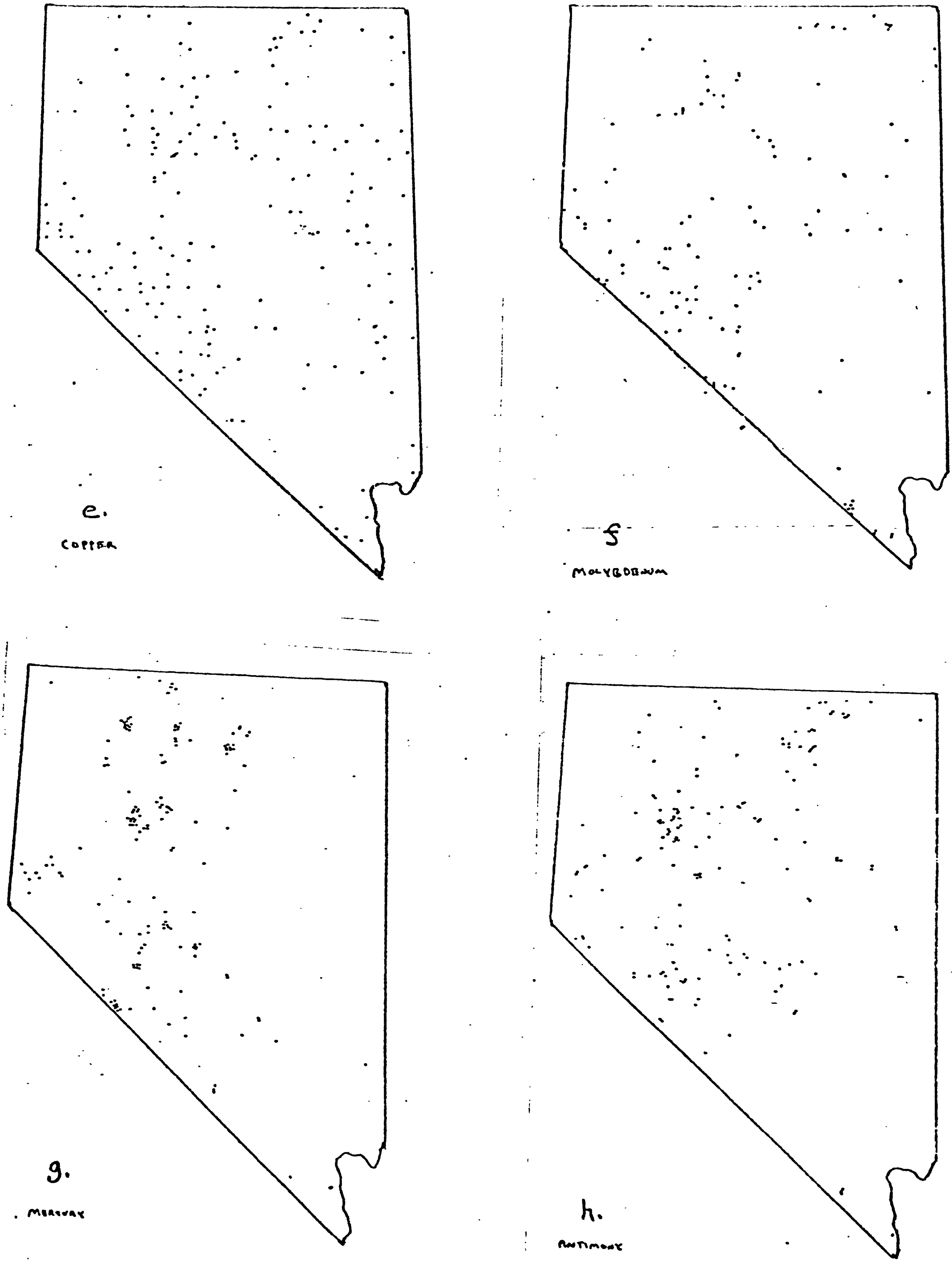


Fig. 11 e-h

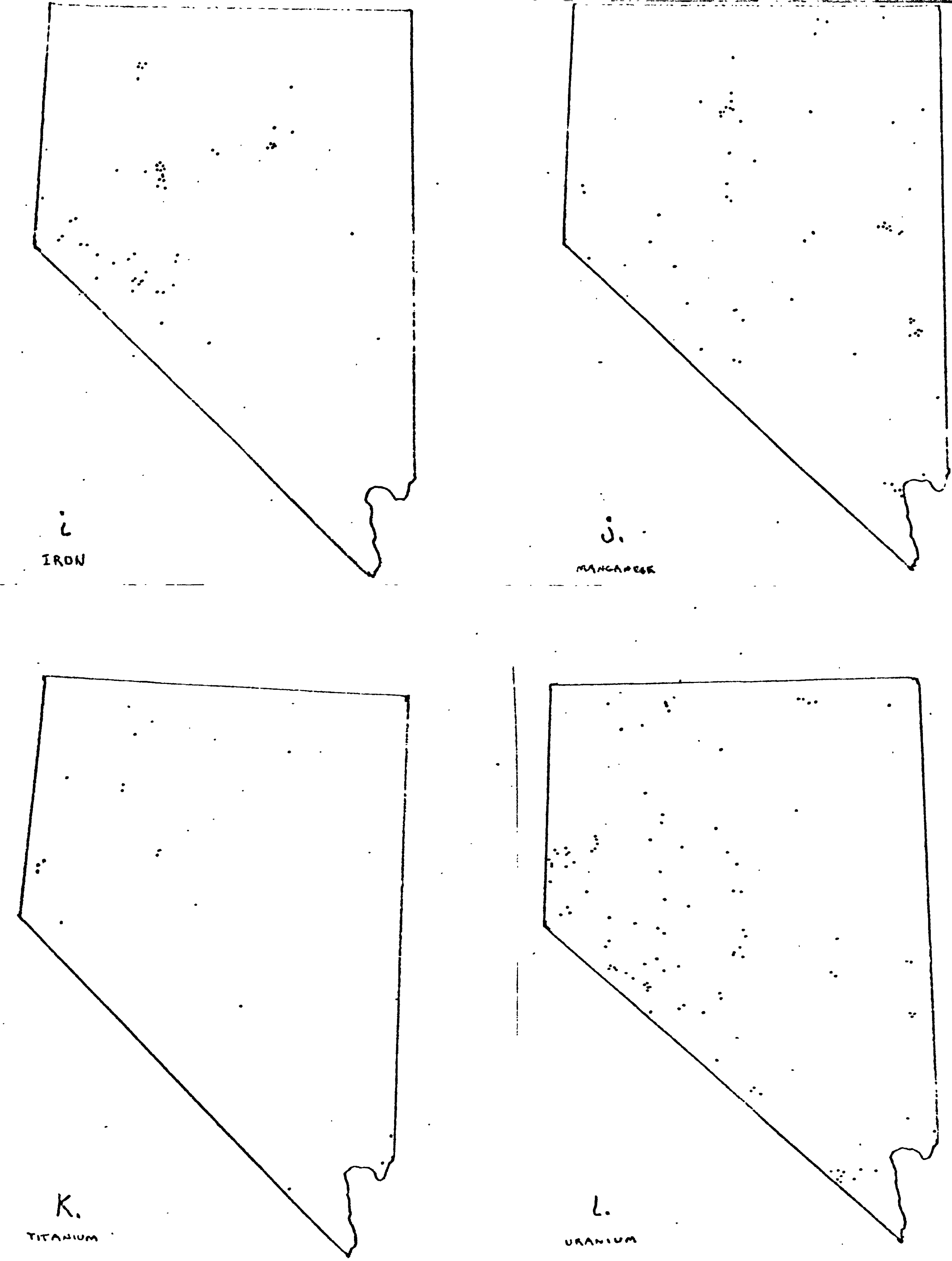


Fig. 11 i-l

southern Nevada-Utah gap by Jerome and Cook (1967). The other two metal-poor areas help in part to define a subtle expression of the Midas Trench lineament system on the maps of gold and silver distribution (fig. 11a and 11b).

It is probably significant that the two individual metal-distribution maps in which linear trends are most distinctive are the mercury and antimony-distribution maps. Most mercury and antimony deposits seen today are fairly young, because they occur at shallow depths and are therefore more easily eroded, and because they are especially susceptible to remobilization (White, 1967). These deposits should therefore reflect the influence of recently active structural zones, such as the ones we believe the lineament systems represent. The Midas Trench lineament system and the Walker Lane are apparent on the mercury-distribution map; the Midas Trench lineament system and an east-trending zone in southern Nevada that aligns with the Pancake Range lineament system are distinctive on the antimony-distribution map. On the other hand, districts of greater ages may obscure definition of distinctive linear trends on the other metal-distribution maps because (1) some ore districts will have formed unrelated to lineament systems through geologic time, and (2) older districts that are related to the lineament systems will have been influenced by the then-active faults, which were probably different from those active today. Periodic reactivation of different areas within the structural zone may account for the breadth of the structural zones, as well as for the diffusivity of the ore districts.

Outside of these few correlations, the metal districts show little or no systematic distributions when examined element by element. Therefore, the areal distribution of known metal mining districts in Nevada were subsequently examined collectively on the assumption that the combined data might highlight any preferential localization of metals.

The contour map of metal mining (Au, Ag, Zn, Pb, Cu, Mo, W, Mn, Fe, Co, Ni, Pt, Pd, Sb, Hg) districts in Nevada (Horton, 1964) was prepared by counting the number of districts within 400 sq. km gridded areas, converting to areal percent, and contouring (fig. 12) (Rowan and Wetlaufer, 1975). The most striking aspect of the distribution of ore deposits in southern Nevada is the dominance of easterly trends (fig. 12). The Pancake Range lineament system (B, fig. 12) and the Warm Springs lineament system (C, fig. 12) roughly bracket the northernmost of the two broad east-trending zones of high ore-district concentration in southern Nevada. The northern boundary of the southern east-trending zone aligns with the western extension of the Timpahute lineament (D, fig. 12) although no concentration of mining districts correlates with the lineament itself. The Timpahute lineament system, as well as the Pahranagat lineament system, terminates at or within a broad north-trending zone of low ore density that traverses the State of Nevada and lies partially in the "Quiet Zone" (Stewart and others, 1977); the Pancake and Warm Springs lineament systems terminate west of this zone.

Although the northwesterly trend of the Walker Lane is only weakly apparent along its northern and central parts, two of the six areas of particularly high ore density (>1.5-2.1 percent) occur in the Walker

Figure 12 - Contour map of the areal density of metal mining districts in Nevada (original data from Horton, 1964) and the major lineament systems delineated in figure 3. (n = 344)

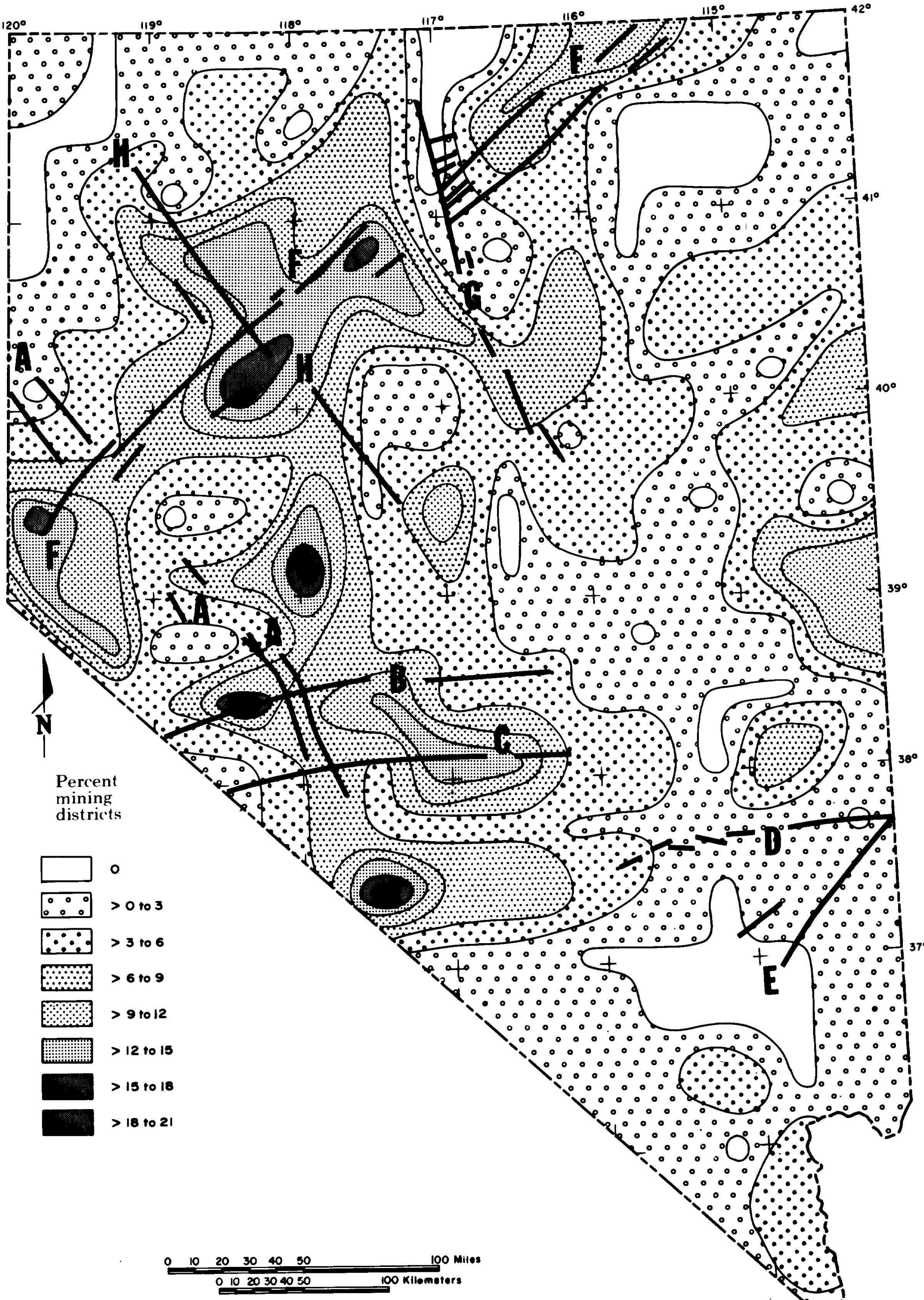

120°
119°
118°
117°
116°
115°
42°
41°
40°
39°
38°
37°
A
B
C
D
E
F
G
H
N
Percent mining districts
0
> 0 to 3
> 3 to 6
> 6 to 9
> 9 to 12
> 12 to 15
> 15 to 18
> 18 to 21
0 10 20 30 40 50 100 Miles
0 10 20 30 40 50 100 Kilometers

Fig. 12

Lane where the two east-trending zones of high ore density intersect it. The extension of the Walker Lane south of these east-trending zones is conspicuously lacking in known ore deposits and denotes the southern Nevada-Utah gap.

The two concentrations of highest ore density in northern Nevada, both of which trend northeasterly, are part of a striking alignment of high mining-district concentration along a broad northeast-trending belt that is coincident with the Midas Trench lineament system (F, figs. 9 and 12). The southernmost of the two high (>1.5-1.8 percent) ore density concentrations in northern Nevada marks the intersection of the Rye Patch lineament system (H, fig. 12) with the Midas Trench lineament system. The northwesterly trend of the Rye Patch lineament system is also apparent, but only north of its intersection with the Midas Trench system. However, Roberts (1966) identified a northwest-trending mineral belt, the Lovelock-Austin belt, which is coincident with the southern three-quarters of the Rye Patch lineament system.

The northernmost concentration of highest ore density in northern Nevada coincides with the intersection of a northwest-trending mineral belt with the Midas Trench lineament zone which is not reflected by lineaments on Landsat images. This belt is known as the Battle Mountain-Eureka belt (Roberts, 1966; Horton, 1966; Noble, 1974; Shawe and Stewart, 1976). It is notable that concentrations of metal districts along the Battle Mountain-Eureka belt and the Rye Patch lineament system do not extend beyond the broadly defined Midas Trench zone to the northwest, even though Tertiary volcanic and Cretaceous plutonic rocks with which the ore deposits are commonly associated are widespread to the north of the Midas Trench system. We believe that the Midas Trench system exerted the primary control on the localization of ore districts in northern Nevada and that the Rye Patch system and the Battle Mountain-Eureka mineral belt are second-order features.

The remaining two of the six areas of high ore density occur at the easternmost and westernmost boundaries of the zone of intersection of the Walker Lane with the Midas Trench lineament system in west-central Nevada. The northerly trend of the easternmost concentration probably reflects the Churchill Arc (fig. 9). The Northern Nevada Rift shows distinctly along its northern part in figure 12 as a 50 km-wide north-northwest-trending gap of low ore density across the Midas Trench lineament system. This negative correlation with ore districts is due, at least in part, to the presence of a 20 km-wide and 100 km-long north-trending alluvial valley. This valley may itself be related to the rifting along the Northern Nevada Rift; the presence of ore deposits beneath the valley cannot be ruled out. Although the lack of correlation of metal-mining districts with the Northern Nevada Rift lineament system, as well as with the Pahranagat lineament system, does not preclude the possibility that ore deposits exist there, it does serve to emphasize the caution and careful analysis needed in evaluating ore distribution maps with respect to lineaments.

The distribution of metal-mining districts weighted according to dollar value was also examined (Rowan and Wetlaufer, 1975) in order to evaluate whether size of the deposits affected the trends of the metal-district concentrations. The resulting density contour map is not illustrated here because it is so similar to figure 12. Like in figure 12, high areal density of dollar-weighted mining districts is most prominent along two broad belts coincident with the Walker Lane and Midas Trench and reflects an east-trending grain in the central part of the Walker Lane. The east-trending concentrations in southern Nevada are considerably more distinctive on the contour map of dollar-weighted mining districts than on the unweighted contour map (fig. 12). The two east-trending zones at 39° and 40° latitude along the eastern Nevada border are also more prominent on the dollar-weighted contour map than in figure 12; these two zones correlate with the Cherry Creek and Hamilton-Ely mineral belts of Roberts (1966).

Discussion of Mineral Belts

The metal mining district density-contour map (fig. 12) suggests that the spatial distribution of ore deposits in Nevada is related to three broad zones which respectively trend northwesterly and easterly in southern Nevada and northeasterly in northern Nevada. These broad zones are more narrowly reflected by six of the eight lineament systems delineated on Landsat images of Nevada (figs. 3 and 9).

Of the numerous mineral belts which have been proposed for Nevada in the past, the northwest-trending Walker Lane has been cited most often. The spatial association of mineral deposits along the Walker Lane has been defined previously on the basis of Precambrian tectonic elements (Roberts, 1966; Horton, 1966) and by the dating of selected Mesozoic and Cenozoic base and precious metal ore deposits (Silberman and McKee, 1974; Silberman and others, 1976; Shawe and Stewart, 1976).

The most widely accepted east-to-east-northeast-trending mineral belt is the Pioche mineral belt in southern Nevada (Roberts, 1966). This belt is reflected by the roughly circular area of high density of ore deposits in eastern Nevada at 38° latitude. The precise location and width of the belt has varied (Roberts, 1966; Shawe and Stewart, 1976, Stewart and others, 1977); two definitions of this belt include lineament system D (Shawe and Stewart, 1976; Stewart and others, 1977). The Wah Wah Tushar mineral belt in western Utah (Hilpert and Roberts, 1964) probably represents the eastward extension of the Pioche mineral belt (Roberts, 1966; Shawe and Stewart, 1976). If the Pioche mineral belt and the east-trending belts of high ore density present to the west are taken together, the east-trending mineral belts form a broad zone 150 km wide across southern Nevada (fig. 9).

The breadth and horizontal extent of the northeast-trending mineral belt in northern Nevada (fig. 12) was first documented by Rowan and Wetlaufer (1975). Roberts (1966) previously identified a short narrow segment, which he called the Shoshone belt, along the central portion of this broad mineral belt. Shawe and Stewart (1976) have more recently also noted this mineral belt across northern Nevada. The breadth of the belt, as seen in figure 12, is consistent with that defined by geological and geophysical data (fig. 9). Although the regional importance of the northeast trend in northern Nevada with respect to influence on ore distribution has long been overlooked, numerous northeast-trending mineral belts have been noted in other parts of the western United States. These belts include the Colorado mineral belt (Tweto and Sims, 1963; Warner, 1978); the transverse porphyry copper belt in Idaho and Montana (Jerome and Cook, 1967); the New Mexico mineral belt (Jerome and Cook, 1967; Raines, 1978); several belts of fluorite deposits (Van Alstine, 1976), one of which lies approximately along the northern margin of the broad belt defined by the Midas Trench lineament system; and three belts of high trace-element content of chalcopyrite and sphalerite from 172 mining districts (Burnham, 1959). In addition, northeasterly trends, as well as easterly and east-northeasterly trends, have been identified in Utah from strike-frequency analysis of faults as most favorable for mineralization (Stokes, 1968).

It must be noted that the compilation of ore districts has not considered age of the deposit nor host rock associations. Alignment of ore districts along the lineament systems would be expected to cover a broad range of ages if these systems do represent old, periodically reactivated zones of structural weakness. At least three periods of mineralization appear to have occurred along the Midas Trench lineament system. Cretaceous tungsten deposits associated with the granitic intrusives (fig. 7) occur along this zone (Guild, 1978), and precious metal deposits along this lineament system show a bimodal distribution of ages of early Oligocene and mid-Miocene (Silberman and McKee, 1974). It is not surprising that metal deposits along the Battle Mountain-Eureka belt have similar trimodal age distributions (Silberman and McKee, 1974; Guild, 1978) because this belt lies within the Midas Trench lineament system and is probably a related second-order feature.

This relationship may indicate that the northwesterly trend was active during early Oligocene time, then somewhat obscured by the northeast-trending mid-Miocene volcanic rocks. Along the Walker Lane, ages of precious metal mining districts span a broad range, from 25-5 m.y. (Silberman and McKee, 1974). The variety of host rocks of the variably aged deposits within these structural zones is not surprising because the environments of deposition are invariably changing between the different periods of reactivation. The location, trend, breadth, and horizontal extent of the mineral belts apparent on the contour map of metal mining districts (fig. 12) are themselves the best arguments for the concept that localization of many ore deposits in Nevada have been controlled by three broad structural zones which are reflected by six of the eight lineament systems defined on Landsat images (fig. 3).

CONCLUSIONS

The areal distribution of faults with respect to azimuth, field relationships, and diverse geophysical data indicate that the seven major lineament systems which are characterized by shearing (A, B, C, D, E, F, H, fig. 3 and table 1) are morphological and tonal expressions of substantially broader crustal features whose locations and trends were inherited from pre-existing structures. The alignments of morphological and tonal features seen in Landsat images were formed during two Cenozoic episodes of generally east-west extension of the Great Basin approximately 17-14 m.y. and 14-6 m.y. ago. Volcanism was active within these broad zones during a 17-6 m.y. period, and many of the most important metal districts are contemporaneous with this volcano-tectonic episode. Moreover, basaltic volcanic rocks younger than 6 m.y. are scattered along the Midas Trench system, Walker Lane, and along the northeastward extension of the Pahranagat system. Concentrations of inherently young mercury and antimony districts along the Midas Trench system and Walker Lane are further evidence of the continuing influence of these crustal zones during the latter part of the Cenozoic era. Coincidence of the Battle Mountain High with the Midas Trench system and its northeastward extension also document this broad crustal zone as a region of magmatic activity.

Intersection of these seven lineament systems without apparent displacement and relationships of fault density patterns suggest that the lineament systems interacted in a conjugate fashion, at least since mid-Miocene time when development of basin-range topography was

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initiated. Northwesterly-trending systems are dominated by right-lateral, strike-slip movement, whereas northeasterly and east-to-east-northeasterly-oriented features are characterized by left-lateral, strike-slip displacement. The Northern Nevada Rift was not an element of the conjugate shear system. Instead, it is an extensional feature that may have served as an axis of spreading during the 17-14 m.y. period. The paucity of metal districts along the Northern Nevada Rift may be related to the different tectonic conditions that prevailed along this narrow zone and to its geomorphic character.

Regional relationships suggest that the seven lineament systems characterized by shearing were established at least by the Mesozoic era and perhaps as early as the Precambrian. The Midas Trench system, for example, appears to have at least influenced the distributions of Cretaceous plutonic rocks and associated metal deposits, as well as post-mid-Miocene volcanic rocks and the metal deposits associated with these rocks. Such episodic reactivation with attendant metallization probably explains the great breadth of these zones and the wide range of ages of metal districts within them.

The general paucity of metal districts along the Pahranagat system emphasizes the importance of other factors, such as host rock composition and texture, structural and erosional activity that may obscure or remove deposits, composition of intrusive rocks, and compositional variations within the mantle. Thus, it is important to note that some metal districts are not located within these broad crustal zones due to the influence of other factors. Nevertheless, the spatial and temporal relationships among the distributions of metal districts and of faults and intrusive rocks show that repeated tectonism and magmatism were essential for developing the major regional metallogenic belts in Nevada.

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