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SPECULATIONS ON GEOLOGIC STRUCTURES IN NORTHERN CALIFORNIA AS DETECTED FROM ERTS-1 SATELLITE IMAGERY

by

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ABSTRACT

Photogeologic examination of repetitive multispectral ERTS-1 imagery of Northern California has disclosed several systems of linear features which may be important for the interpretation of the structural history of California. Four linear systems co-exist within the northern Coast Ranges. They are separated from an orthogonal system of linears in the Klamath Mts. by a set of discontinuous southeast-trending linear features (the Mendocino system) which is traceable from the Pacific Coast, at Cape Mendocino, into the eastern foothills of the Sierra Nevada. Within the Sierra Nevada, the Mendocino system separates the north-trending Sierran system from a set of linears characteristic of the Modoc Plateau.

With minor exception, little overlap exists among the systems which suggests a decipherable chronology and evolutionary history for the region. The San Andreas system of linears appears to truncate or co-exist with most of the other systems in the northern Coast Ranges. The Mendocino system truncates the Klamath, Sierran and Modoc systems. The Sierran system may represent fundamental and long-persisting pre-late

ACCOMPLISHMENTS:

Although the Principal Investigator was on sabattical leave from September 23 to December 1, 1973, the Research Assistant continued on the project. Thus during the reporting period (July 1 to December 20, 1973) the following progress toward the objectives of the project can be reported:

1. Preliminary structural, lithologic, and geomorphic maps have been completed using imagery received from September 1972 to September 1973. These maps are being analyzed and prepared for the final report.

2. Field trips were made to ground check several selected areas and to substantiate or revise interpretations made from the imagery. Observations made during these trips have verified several photo interpretations made from ERTS-photography but required modification of others. Significant in the latter respect was the influence of vegetation (particularly type and size of trees) in the various microclimates on the detectibility of geologic features.

3. Preliminary work on correlation of geologic structural features (linears on ERTS-photos) and known locations of metallic ore deposits of various kinds shows promise, but the work has not advanced far enough for definitive statements.

4. Prepared manuscript for publication in scientific journal (Preprint copy attached).

SIGNIFICANT RESULTS:

1. See attached preprint of manuscript.

2. A preliminary geomorphic analysis of the Northern Coast Ranges (Fig 1) discloses that the geomorphic characteristics of the area underlain by the Coastal system of linears are much different from those associated with the Central linear system in the core of the Coast Ranges. Within the Coastal system, or Coastal belt, the drainage networks are moderately fine-textured and have moderately high-density. Although many of the master drainages are parallel with the Coastal linear system, the headward tributaries form a modified directional trellis pattern. The topographic "grain" of the Coastal belt is in part controlled by the San Andreas fault and its associated subsidiary fault zone; however, east of the San Andreas Fault zone the topographic "grain" or texture is slightly oblique to the fault, appears to be made up of a crudely aligned ridge and valley topography, and the effective relief is moderate.

The drainage network within the Central System is coarse-textured and of relatively low-density. The drainage has developed no definite pattern (classified here as deranged) although in parts of the area (i.e. San Francisco Bay region and near the southern boundary of the Klamath Mts: Frame 1094-18231 and 1095-18283) a subparallel or colinear drainage pattern can be detected. The topographic "grain" of the area is poorly defined, but locally is controlled by the north-northeast trending Central system of linears. The topographic relief in the area ranges from about 500 to 7000 feet above sea level.

From these data and from direct photogeologic interpretation of the imagery, the region associated with the Coastal system appears to be underlain by rocks which are similarly resistant to erosion and were structurally deformed in a uniform manner. The area associated with the

Geomorphic Regimes Northern California, C-Coastal; F-Franciscan; M-Metamorphic; K-Klamath Mt.; G-Great Valley; P-Modoc Plateau; S-Sierra Nevada; B-Basin and Range.

Central system seems to be underlain by an heterogeneous assemblage of rock types which vary ~~in~~ their resistance to erosion and the structural deformation appears much less uniform and more disordered although locally it is subparallel to the linears.

The boundary between the Coastal and Central geomorphic regions is poorly defined and, in a few places, the two regions can be separated only approximately. In general, however, the boundary follows the courses of some of the master drainages of the Northern California Coast Range, namely the estuarian system of Tallma Creek near San Francisco, the headwaters of the Russian River from Healdsburg northward, and main stem of the Eel River in its headwaters to the Pacific Coast near Cape Mendocino, northern California. North of Cape Mendocino the Central system borders the coastline. The eastern boundary of the Central geomorphic regions is sharp and clearly defined. It forms a sinuous belt of contrasting topography along the western edge of the Sacramento Valley.

The geomorphic character of the region just east of the Central system of lineations is one of fine-textured, high-density drainage with a well developed trellis drainage pattern. The topography of the region is characterized for the most part by north-trending valleys and ridges associated with the sedimentary rocks of the Late Mesozoic Great Valley sequence. The topographic "grain" of the area trends northward.

On the basis of very preliminary geomorphic data from ERTS, a review of existing geologic maps and reports, and the relation with ERTS-detected linear systems, the following working hypothesis has been formulated:

1. In the southern part of the project area the Valley system of linear elements crosscuts both the Central and Coastal systems and thus may be the youngest of the three linear features. From the ERTS imagery, the geomorphic character and the linear features associated with the Central system terminate abruptly at the boundary with the Coastal system. This suggests that the Central system of linears is older than the Coastal system. Hence, the chronologic order of development of the three systems is, from oldest to youngest: Central system, Coastal system, and Valley system.

2. Many areas within the region underlain by the Central system are known to contain thrust klippen of sedimentary rocks of the Late Mesozoic Great Valley sequence (Rich, 1970, 1971; Swe and Dickinson, 1970; Bailey, Blake, and Jones, 1970; Jones and Irwin, 1971), particularly in the vicinity of Lake Berryessa, Clear Lake, Lake Pillsbury, and the southern margins of the Klamath Mts. The combination of the poorly defined topographic "grain", deranged drainage networks, heterogeneity of rock types, and known overthrust klippen suggest an extremely complicated geologic and geomorphic history within the core of the Coast Ranges. The Central system of linear features and associated geomorphic characteristics thus may represent the mélange of the Late Mesozoic-Early Tertiary subduction zone along the northern coast of the U.S.

3. The Coastal system of linear features and characteristic topographic depression may have developed in association with the movement along the San Andreas Fault, which according to Atwater (1970) dates from Mid-Tertiary (29 M.Y.B.P.).

In summary, the recognition of the ERTS imagery of the linear systems in the Northern Coast Ranges and Sacramento Valley and the geomorphic characteristics within the regions defined by these systems suggests a reasonable geologic interpretation consistent with the known geology of the region. If this interpretation should prove valid, the location of, and the time of emplacement of, economic deposits within the region may be more clearly defined.

Paleozoic zones of crustal weakness which have been reactivated from time to time. The Mendocino system was possibly developed in early Mesozoic and is important to the structural framework of Northern California.

INTRODUCTION

Photogeologic examinations of low-altitude aerial photographs (or photo mosaics constructed from these photos) have been performed by many geologists but, with few exceptions, the results from these studies have not been published. Regional studies using low-altitude aerial photography may be complicated by the large numbers of photos requiring examination and by the fact that large regional features may be masked by, or may form the background for, finer-detailed features. The ERTS-1 (Earth Resources Technical Satellite-1) photography, however, provides an accurate small-scale photo of a large segment of the earth's surface on which many of the finer-detailed features are less well defined and the regional characteristics are emphasized or made more readily detectable. The repetitive multispectral ERTS photography makes it possible to evaluate regional features at the photographically most advantageous times of the year with regard to the character of the vegetative cover, sun-angle, and sun-azimuth.

The purpose of this report is to present the authors' preliminary analysis of ERTS-1 satellite photography of Northern California and to make the data available to geologists engaged in detailed mapping in the region or in speculating on the geologic history of California.

Because of the uncertainty inherent in photogeologic interpretation, geologists who are familiar with or who have mapped specific areas on the ground may question a few of the authors' interpretations, but it is hoped that the data may prove helpful to them and to others, and encourage a reexamination of current geologic interpretations in light of the data presented here.

Figure 1 is a small-scale uncontrolled mosaic of northern California prepared from ERTS photography. Figure 2 is a diagrammatic sketch of the physiographic provinces included in Figure 1.

Figure 3 is a composite of the authors' interpretation of the linear features whose positions were determined after an examination of about 200 individual photographs obtained during repetitive passes of the satellite over Northern California for the time period September 1972 to July 1973. Six to twenty photos of any specific area were examined (the number of photos per area is variable because of the percentage of cloud cover over the area during the orbits of the satellite); hence the seasonal changes in sun-azimuth and sun-angle and the seasonal vegetational changes were considered and evaluated. The data from the photos were compiled on a working map at a scale of 1:500,000 by projecting the original 1:3.4 million scale 70 mm positive transparencies through a standard classroom 3 1/4" x 4 1/4" projector onto a translucent frosted-glass screen.

LINEAR FEATURES

The linears shown on Figure 3 include such features as the alignment of streams or segments of streams, of offsets along several adjacent streams, of consecutive ridge-spurs, anomalous alignment of groups of topographic features (such as continuous straight ridge crests that align with anomalously straight reaches of streams), alignment of tributaries over rather long distances, of saddles in ridges; in short, all of the criterion used in geologic and photogeologic work to indicate fracture, joint or fault systems. Sharp linear tonal-contrasts were included on the map as linear features only if they could be identified on two or more sets of photographs taken at different times of the year. Linear features commonly associated with bedding in sedimentary rocks were excluded unless the bedding was offset or appeared to be truncated along a persistent linear zone. Except in a few instances, nearly horizontal planar features, such as thrust faults, could not be detected unless they separated rocks with gross lithologic differences (tonal and textural difference on the photos) or the surface traces of the planar elements coincided with, or formed, linear or other anomalous topographic features. Linear man-made features such as roads, power lines, irrigation ditches, and field boundaries were carefully excluded.

Although the criterion used to define the linear features shown on the map are those commonly used to define the linear feature shown on the map are those commonly used to photogeologically define fractures, joints, or faults, the geologic reason for each of the linear features observed on the ERTS photos is not known. However, because of the care with which each was evaluated by the authors, they are assumed to be geologically controlled and a geologic explanation for them should be investigated in the field.

Figure 4 is a tracing of all of the faults in Northern California that have been recorded on the Geologic Map of California (California Division of Mines and Geology, preliminary map of California, used with permission) and is included here for comparison purposes. The solid lines on Figure 3 represent those linear features which exactly coincide in location with faults shown on figure 4. The large number of ERTS-detected linear features that coincide with known faults lends credence to the assumption that the linear features are geologically controlled. Other similarities or differences in the linear patterns become apparent when these two maps are compared.

It is not the intent of this paper to discuss each of the linear features but rather to point out some of the gross linear patterns and suggest possible relationships among the patterns. The linear patterns may be divided into several linear systems defined on the basis of their surface trends and their relation to adjacent systems. Some of the systems are parallel with the topographic grain of the area, and this relationship has been long recognized by geologists working in the region. Other systems cut across the topographic grain or are oblique to it and, in some instances, have not been recognized or described in the available literature. The linear systems and their geographic extent are diagrammatically summarized on figure 5 and briefly described below.

LINEAR SYSTEMS

The linear pattern in the northern California Coast Ranges is particularly complex and differs from those in Klamath Mts., Modoc Plateau, and Sierra Nevada physiographic provinces; however, it is possible to subdivide the Coast Range pattern into distinct linear systems. Within the southern one-third of the Coast Ranges, extending from the latitude of San Francisco Bay to just north of Clear Lake and from the Pacific Coast to the western edge of the Sacramento Valley, four co-existing linear systems predominate. First, the San Andreas System is made up of northwest-trending linear features more or less parallel with the San Andreas Fault zone and includes the Hayward Fault and several smaller linear features whose trend is subparallel to the San Andreas Fault. On the basis of topographic expression and tonal contrast observed on the ERTS photography, the authors suggest (Figure 3) that the northern extension of the Hayward Fault is west of and extends farther north than has been previously recorded. Secondly, the Coastal System comprises a set of west-northwest linear features confined primarily to rocks of the Coastal Belt Series between the San Andreas and Hayward Faults. Individual linear features of the Coastal System do not extend west of the San Andreas Fault zone and with only a few exceptions do they extend east of the Hayward Fault. The trends of these linears are crudely parallel with the topographic grain of the area. Third, the Central System, which is made up of north-northeast trending linear features, is confined to the central core of the Coast Range and involved rocks assigned to the Franciscan assemblage and Coastal Belt (Bailey and others, 1964). The trends of individual linear features within the Central System are more variable than those in the previously described systems, but nevertheless they are sufficiently distinct from the other systems to suggest a different set of geologic circumstances for their origins. Lastly, the Valley System, an east or east-northeast trending systems of linears, appears to crosscut all of the other systems and locally extends from the Coast Ranges into and across the Sacramento Valley. The linears included in the Valley System have not been previously recorded in the published literature available to the authors, but have been described in unpublished reports (Lattman, personal communication).

About 30 miles (48 km) north of the latitude of Clear Lake linear features of the Coastal and Valley Systems diminish in number and are replaced northward, in the Coast Ranges, by linear systems more closely associated with the Klamath Mts. or with a belt of metamorphic rocks associated with the Coast Range thrust (Bailey and others, 1970). The San Andreas System persists northward to Cape Mendocino, although it is less clearly defined at and north of the Cape. The termination of the Coastal and Valley Systems north of Clear Lake suggests a change in the underlying geologic structure. The fault map (Figure 4) shows a dimunition of known faults in this region but this may be due to the lack of adequate detailed mapping in the area.

The east-southest trending discontinuous set of linear features, here referred to as the Mendocino system, is traceable from the Pacific

Coast at Cape Mendocino, across the northern end of the Sacramento Valley and into the eastern foothill belt of the Sierra Nevada. Although individual linear features within the Mendocino System are discontinuous, the system as a whole represents a wide belt separating regions with distinctly different linear patterns. In the Coast Ranges, the region south of the Mendocino System consists of the San Andreas and Central Systems; north of the Mendocino System, the region is dominated by an orthogonal set of linears associated with the Klamath Mts. In the Sierran foothills, the Mendocino System separates systems of linears associated with the plutonic rocks of the Sierra Nevada from those associated with the Late Tertiary volcanic rocks of the Modoc Plateau. The Mendocino System, therefore, may be significant in the interpretation of the structural framework of northern California.

Within the Klamath Mt. province, an orthogonal system of linears, one set of which trends east-northeast and the other set of which trends north or a few degrees west of north, is referred to as the Klamath System. It is bounded on the south by the Mendocino System and on the west by curvilinear features, which by comparison with figure 4 are probably a series of thrust faults. Cursory examination of the ERTS photography suggests that the Klamath System extends northward into Oregon, but the photogeologic mapping by the authors has not clearly defined a northern limit. The Klamath System appears to terminate rather aburptly just east of Shasta Reservoir along a poorly defined north-trending zone where the orthogonal pattern of the Klamath System changes to one whose trend is predominantly north-northwest - the Modoc System of this report.

The linears in northeastern California are referred to as the Modoc System and have been long recognized (Hinds, 1952). This system, which extends from the vicinity of Lake Tahoe northward to Goose Lake and into Oregon (Figure 3), consists of short, discontinuous, generally northwest-trending linears that in gross aspect form an orderly pattern. A zone of linears along the western margin of the Modoc System has a persistent north-northwest trend, but it is included here within the Modoc System because its trend more closely parallels those of the Modoc System than it does other systems in the area. Between Lake Tahoe and Honey Lake, along the eastern border of California, a few linears trend east-southeast sub-parallel with the Mendocino System. These linears may represent an eastward continuation of the Mendocino System.

The western slope of the Sierra Nevada, between Lake Tahoe and the eastern edge of the Sacramento Valley, is characterized by linears whose trend is only a few degrees east of north. These linears, are referred to as the Sierran System. The few east-trending linears within the Sierran System may represent extensions of the Valley System from the Coast Ranges into the Sierras; however, only a few of them can be traced across the alluviated Sacramento Valley.

The Sierran System is truncated on the north by the Mendocino System, on the northeast by the Modoc System, and on the south and west by a fairly continuous set of linears along the eastern margin of the

Sacramento Valley (Malones Fault zone?). The truncation of the Sierran System at the edge of the Sacramento Valley may be more apparent than real because it is difficult to detect and verify linear features within the alluviated part of the valley.

Other linear features shown on figure 3 do not appear to be related to any of the above systems. For example, broad zones of short discontinuous linears confined to, or associated with, subtle tonal changes on the ERTS photographs are depicted on figure 3 by lines of small open circles. The most conspicuous of these zones trends northeast across the southern part of the Sacramento Valley. Other such zones are near the junction of the Mendocino and Modoc Systems and in the vicinity of Goose Lake in northeastern California. Although these features may be subparallel with the Valley System, they are excluded from it because of their different photographic and topograhic characteristics. The linear features bordering both the eastern and western margins of the Sacramento Valley are not included within any of the systems described here. These linear features are subparallel with the western zone of the Modoc System, but they do not appear to be geologically or topographically related to it.

DISCUSSION

Some of the linear features making up the linear systems have been recognized for many years and are documented by published geologic maps (Figure 4). Similarly, some of the linear systems have been recognized but others have not. Speculation concerning the detailed relationship among the various linear systems are beyond the scope of this brief report, but some general observations concerning the regional relations and chronology can be made. The observations discussed here are based on the following assumptions.

The linear features are assumed to be geologically controlled, therefore the linear systems reflect physical and geologic conditions that existed at the time of their development. The authors were not able to check each linear feature within the large area covered by figure 3, but the linears which were field checked, or were previously known to the authors, show fault displacement or are zones of intense fracturing or jointing. The similarity between the trends and locations of many ERTS-detected features and known faults (Figures 3 and 4) strengthens the assumption that the linear features and linear systems are geologically controlled.

The linear features making up a linear system are assumed to have been developed penecontemporaneously and hence their original trend resulted from forces acting at the time of their formation. This does not preclude changes from the original trend by translation or rotation or later deformation along the pre-existing trend, but rather it assumes that once a system is formed any regional changes affect a system as a whole.

Further, it is assumed that one or more systems may be superimposed on another (overprinted), but traces of the original system persist and are reflected, however subtly, in the geomorphic characteristics of the land surface. Clearly, the surface expression of a system may be obliterated by younger undeformed deposits, such as lava flows or alluvial deposits; but it is assumed that surface erosion and later deformation (particularly along pre-existing trends) will not obliterate an older system on a regional scale - in some cases these processes may actually emphasize the surface characteristics. Trends of older linear systems have been detected in overlying sedimentary rocks and alluvium (such as the expression of the Valley and Mendocino Systems through the Tertiary rocks and alluvium of the Sacramento Valley). The detectibility however may be due to the localization of ground water along pre-existing fractures rather than renewed crustal deformations or erosion.

Within the framework of the foregoing description of the linear systems and the assumptions made regarding them,some regional relationships among the systems can be tentatively deduced. With the exception of the southern one-third of the Coast Ranges, most of the systems are separated from one another with only minor overlap. This suggests a decipherable chronologic and evolutionary development of the systems. For example, the Sierran and Klamath Systems appear to terminate at their junction with the Mendocino System and the Modoc System is overprinted by the Mendocino. These relations suggest that the Sierran and Klamath Systems are relatively older than the Modoc System and the Mendocino is the youngest of the four systems. Chronologic deductions such as this may be weakened because of the uncertaintly of the relative age of the Modoc System whose trend may be inherited from an older fracture system beneath the late Tertiary to Holocene lava flows making up the surface rocks of the Modoc Plateau, or may be contemporaneous with, or younger than, the flows. Also, deformation may have recurred through time along the trend of the Mendocino System and the overprint on the Modoc System may merely represent the latest episode of movement. Although chronologic comparisons such as this may be invalid, the spatial relations among the four systems remain and require explanation.

The San Andreas System is pervasive in the northern Coast Ranges and, except for the Klamath System, it appears to truncate or co-exist with other systems. The Coastal System, for example, is confined between the San Andreas and Hayward Fault zones and is probably directly related in time and position to the deformation along these faults. (Might the Coastal System be explained as second-order right-lateral wrench faults with primary penecontemporaneous right-lateral displacement along the San Andreas and Hayward Faults, as suggested by Moody and Hill (1956)?) Possible offset of the Central System by the San Andreas System in the vicinity of Clear Lake and the overprint of the Central System onto the Mendocino and Klamath Systems suggest that the chronologic development of the linear systems in the Coast Ranges is, from oldest to youngest, Klamath, Mendocino, Central and the combined San Andreas-Coastal System.

The Valley System is difficult to fit into the chronologic model presented. It appears to co-exist with all of the systems in the southern one-third of the Coast Ranges, the Sacramento Valley and the Sierran foothills which suggests that it post-dates or is overprinted on the other systems. On the other hand, the imprint of the Valley System on the topography is faint and discontinuous, hence it may be a remnant of a long-persisting linear system which pre-dates all of the other systems. However the authors believe the Valley System represents the youngest of the linear systems because of the fault relations just north of Clear Lake, the overprint in the Coast Ranges of the Valley System on the San Andreas and Central Systems and the Sierran and Mendocino Systems in the Sierra Nevada foothills.

Thus, in summary, the authors suggest that the relative age of the eight linear systems is, from oldest to youngest, the Sierran, Klamath, Modoc, Mendocino, Central, the San Andreas-Coastal systems, and the Valley System. The actual geologic ages of the linear systems must depend on detailed field examination of the linear features and their junctions and the relative ages of the rock units involved. It may be possible, however, to establish some gross limits for the formation of the linear systems. If the geologic relations of the infolded ultramafic and metamorphosed Paleozoic rocks in the Sierran foothills are as suggested by Hietanen (1973), the Sierran System may represent trends that have prevailed since at least late Paleozoic time. Furthermore, the northerly trend of the Sierran System is inconsistent with the geometries of north-south compression proposed by Moody and Hill (1956), with northeast compression (subduction) postulated by Hamilton (1969) and Ernst (1970), or with post-Oligocene transform displacement along the San Andreas fault zone suggested by Atwater (1970). Thus, it is assumed that the Sierran system is not only the oldest of the systems discussed but may have been formed under stresses radically different from those that existed during or following the late Mesozoic. This analysis may be reconciled with late Mesozoic plutonism in the Sierra Nevada by suggesting that the distribution of the plutons may have been controlled by pre-existing zones of crustal weakness. The similarity of trend of the Sierran System and trend of the initial Sr^{87}/Sr^{86} in the Mesozoic granitic rocks in Central California reported by Kistler and Peterman (1973; p. 3490 and fig. 2) and the geologic and geophysical data of these authors tends to support the hypotheses that the Sierran system may have been inherited from pre-late Paleozoic crustal deformation but may have been reactivated during the Mesozoic. On the other hand, if one assumes the Sierran System to be late Mesozoic or younger, the spatial relation between the Sierran Systems and the Mendocino and Modoc Systems must be explained.

Atwater (1970) indicated that transform displacement along the San Andreas may have begun during late Oligocene or early Miocene in the vicinity of Cape Mendocino. We suggest that the linear features making up the San Andreas System probably developed at that time, even though deformation along the San Andreas continues to the present.

The relative age of the Mendocino System is uncertain for locally it is offset by the San Andreas System; it truncates the Klamath and Sierran System and is overprinted onto the Modoc System. If the Sierran System dates from late Paleozoic or even early Mesozoic and the offset of the Mendocino by the San Andreas is assumed to be the result of postlate Oligocene or early Miocene displacement along the San Andreas System then the Mendocino System must have formed sometime in the Mesozoic or earliest Tertiary. The progressively greater amount of displacement in the oldest late Mesozoic rocks relative to that in the youngest late Mesozoic and Tertiary rocks along the western margin of the Sacramento Valley (Page 1966; Bailey and Jones, 1973), the imprint of the Mendocino System on the Modoc System, and the detectibility of the Mendocino System in the alluvium of the Sacramento Valley suggest that recurrent movement along linear features within the Mendocino System has been the rule rather than the exception. The authors, therefore, suggest that the Mendocino System may have existed since mid-Mesozoic and is significant in the interpretation of the Mesozoic structural framework of California.

ACKNOWLEDGEMENTS

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ILLUSTRATIONS

Figure 1. Photomosaic of Northern California made from MSS band 6 (0.7-0.8 micrometers), ERTS-1 imagery.

Figure 2. Physiographic provinces in Northern California. K.M. - Klamath Mts.; C.R. - Coast Ranges; G.V. - Great Valley; C.R. - Cascade Ranges; M.P. - Modoc Plateau; S.N. - Sierra Nevada; B - Basin and Range (from Thornbury, 1965). S.F.B. - San Francisco Bay.

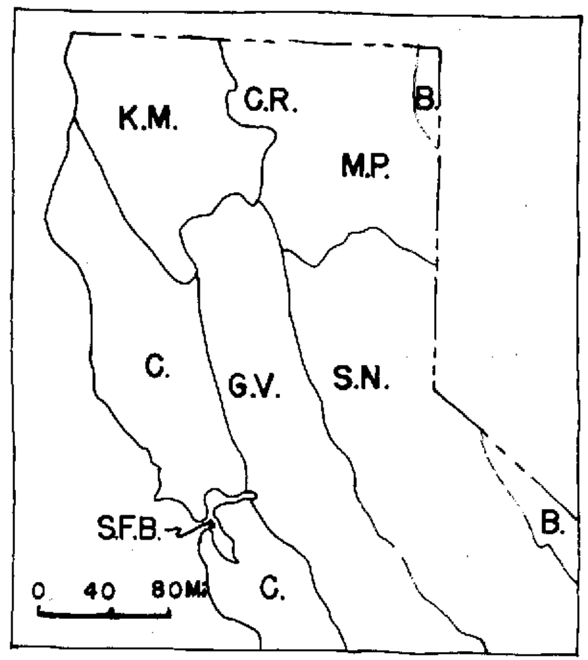
Figure 3. ERTS-identified linear features in Northern California. Solid line - known faults (see figure 4); dashed line - well defined ERTS linear features; dotted line - poorly defined ERTS linear features; line of open circles - zone of linear features or tonal contrast on ERTS imagery. C.M. - Cape Mendocino; SAFZ - San Andreas Fault zone; HFZ - Hayward Fault zone; MFZ - Malones Fault zone; LA - Lake Almanor.

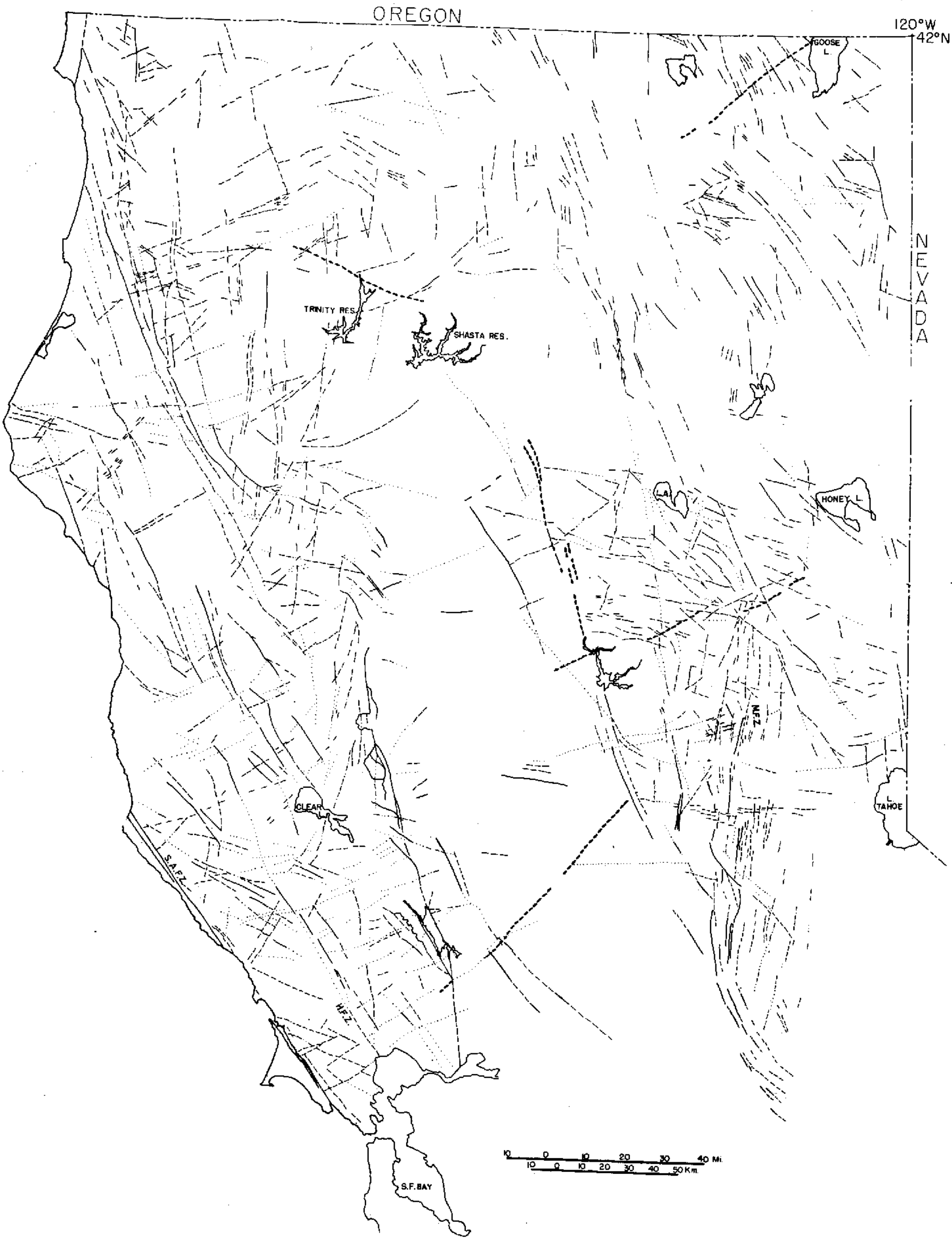
Figure 4. Fault map of Northern California. Solid line - mapped fault; dashed line - probable fault; barbed line - thrust fault; C.M. - Cape Mendocino

Figure 5. Location of linear systems. Patterns: ++'s, San Andreas System; NW-SE diagonal lines, Coastal System; heavy dots, Central System; horizontal lines, Mendocino System; circles, Klamath System; xx's, Modoc System, V's Sierran System; vertical lines, Valley System. Limits of systems approximate only, refer to figure 3 for actual geographic extent.

Fig. 1

Fig. 2





OREGON
120°W
42°N
GOOSE L.
NEVADA
TRINITY RES.
SHASTA RES.
C. M.
L.A.
HONEY L.
M.F.Z.
L. TAHOE
CLEAR
S.A.F.Z.
H.F.Z.
S.F. BAY
10 0 10 20 30 40 Mi.
10 0 10 20 30 40 50 Km.

Fig. 3


OREGON
120° W
42° N
GOOSE L.
NEVADA
TRINITY RES.
SHAST
C.M.
L. ALMANOR
HONEY L.
MALONES FAULT ZONE
L. TAHOE
CLEAR
SAN ANDREAS FAULT ZONE
HAYWARD FAULT ZONE
S.F. BAY
10 0 10 20 30 40 MI.
10 0 10 20 30 40 50 Km.

Fig. 4

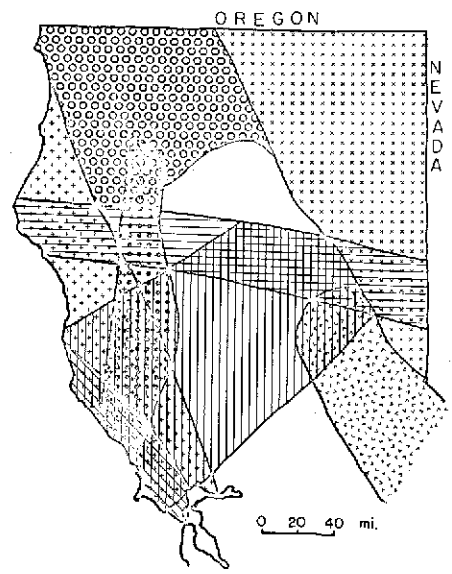


Fig. 5