Neotectonics of the San Andreas Fault System - Basin and Range Province Juncture

NASA Grant NAG 5-177

Final Report

1 May 1981 - 15 March 1986

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(NASA-CR-176562) NEOTECTONICS OF THE SAN ANDREAS FAULT SYSTEM: BASIN AND RANGE PROVINCE JUNCTURE Final Report, 1 May 1981 - 15 Mar. 1986 (California Univ.) 14 p HC A02/MF A01 CSCL 08G

N86-20996

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G3/46 05652

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Introduction

This final report briefly summarizes research at the University of California, Santa Barbara, on National Aeronautics and Space Administration Grant NAG 5-177. As part of the NASA Geodynamics Program, the general objective of our study has been an improved understanding of the tectonic interplay of the southern San Andreas fault system and the Basin and Range province in the vicinity of the Eastern Transverse Ranges of Southern California (Figure 1).

A parallel objective has been to determine the utility of remotely sensed imagery and other spatial data in the analysis of neotectonic patterns. A wide variety of techniques, some standard and some experimental, have been used and it is believed that the findings of this research will be of value both to the earth scientist interested in our study site and to others who might beneficially apply some of the methodologies developed here to other sites. Several parts of this research are being continued and will be published in as-of-yet undetermined media. Publications to date are listed at the end of this report. A detailed and comprehensive report of the findings of this research will be found in the dissertation of R.E. Crippen (1986).

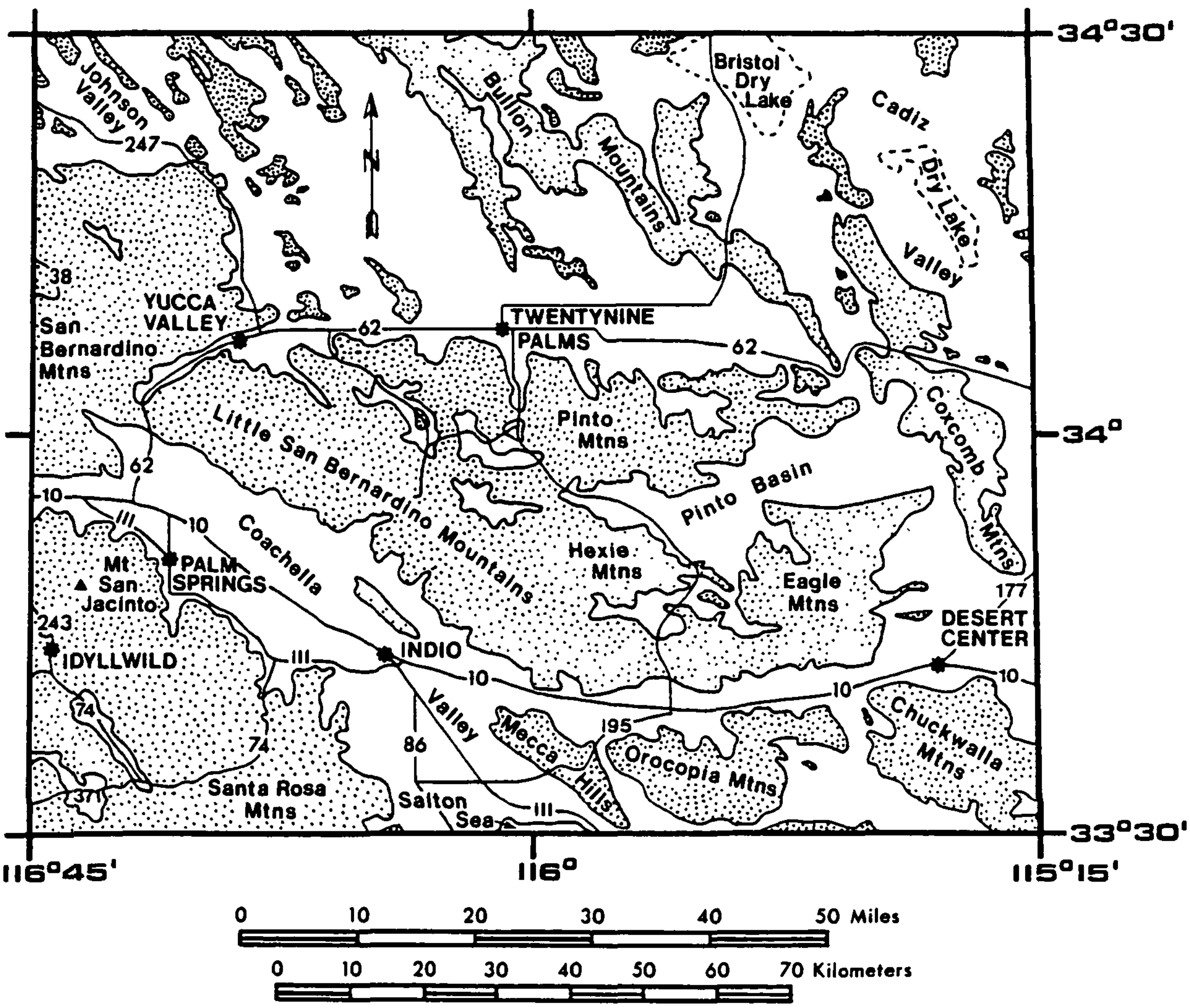
Data Resources and Preprocessing

Several data sets were merged into a Geographic Information System (GIS) format for comparative analyses and extraction of synergetic information. These include (1) digital elevation data, (2) aeromagnetic data, (3) gravity data, (4) earthquake focus data, (5) Heat Capacity Mapping Mission imagery, and (6) Landsat-2 Multispectral Scanner (MSS) imagery. Each was formatted into a north-south, west-east grid of pixels of 10-minute (N-S) and 12-minute (W-E) spacing. This format preserved (actually oversampled) the resolution of the HCMM and geophysical data and resulted in images (360 lines by 450 samples) of pixels approximately 308 meters square. The digital elevation and MSS data were also formatted at 2 1/2 minutes (N-S) by 3 minutes (W-E) to preserve their higher spatial information (about 77 m) for more detailed studies. Additional data sets of irregular or incomplete coverage, not included in the GIS, are (1) large-scale topographic maps, (2) Seasat radar imagery, (3) aerial photographic imagery, and (4) Landsat-4 and Landsat-5 Thematic Mapper (TM) imagery.

Figure 1

STUDY AREA LOCATION INDEX

Selected Towns, Physiographic Features, and Major Highways Indicated



Each data set required its own special preprocessing. Two examples are: (1) one-fourth of the digital elevation data required conversion from UTM to arc-second format, some bad data lines needed replacement by interpolated values, and below sea-level values needed several corrections (NCIC digitization algorithms were not designed to properly handle negative elevations), and (2) each of four aeromagnetic data sets had to be assigned a scale-offset additive term so that their merger would result in continuity across quadrant boundaries.

Background information on geologic mappings, tectonic models, and relevant methodologies were compiled into a computerized, keyword-indexed bibliography of over 600 references (Crippen, 1986).

Field studies were necessary at several sites.

Techniques Summary

Geomorphometrics Research

A quantitative landform analysis technique, shown to be effective in delineating neotectonic features (Crippen, 1983), was further developed and applied to the digital elevation data set. The technique uses a measure of the local correlation of elevation and relief to detect deviations from fluvial geomorphic concavity. Linear correlation is consistent with the logarithmic character of longitudinal stream profiles and has been found to be a close approximation to the general morphology of undisturbed alluviated areas. Deviations from strong positive elevation-relief correlation indicate disruption of common fluvial morphology by non-fluvial (presumably neotectonic) influences.

Figure 2 displays the spatial pattern of elevation-relief correlations. The darker tones indicate areas of poor correlation. Extensive anomalies are present in the Surprise Spring area (34°18'N, 116°13'W) where numerous faults cross alluviated terrain. The anomalies in the San Bernardino, Little San Bernardino, and San Jacinto Mountains appear to border areas of upland surfaces and other products of neotectonic movements.

The limitation of his technique in this particular study was the vertical resolution of the original elevation data. The data were created by digitizing 200-foot contour 1:250,000 scale maps. The technique is good at detecting gentle warps across alluviated areas. However, most such features are lost at this crude resolution. The method will have increased value as new high-resolution digital elevation models become increasingly available.

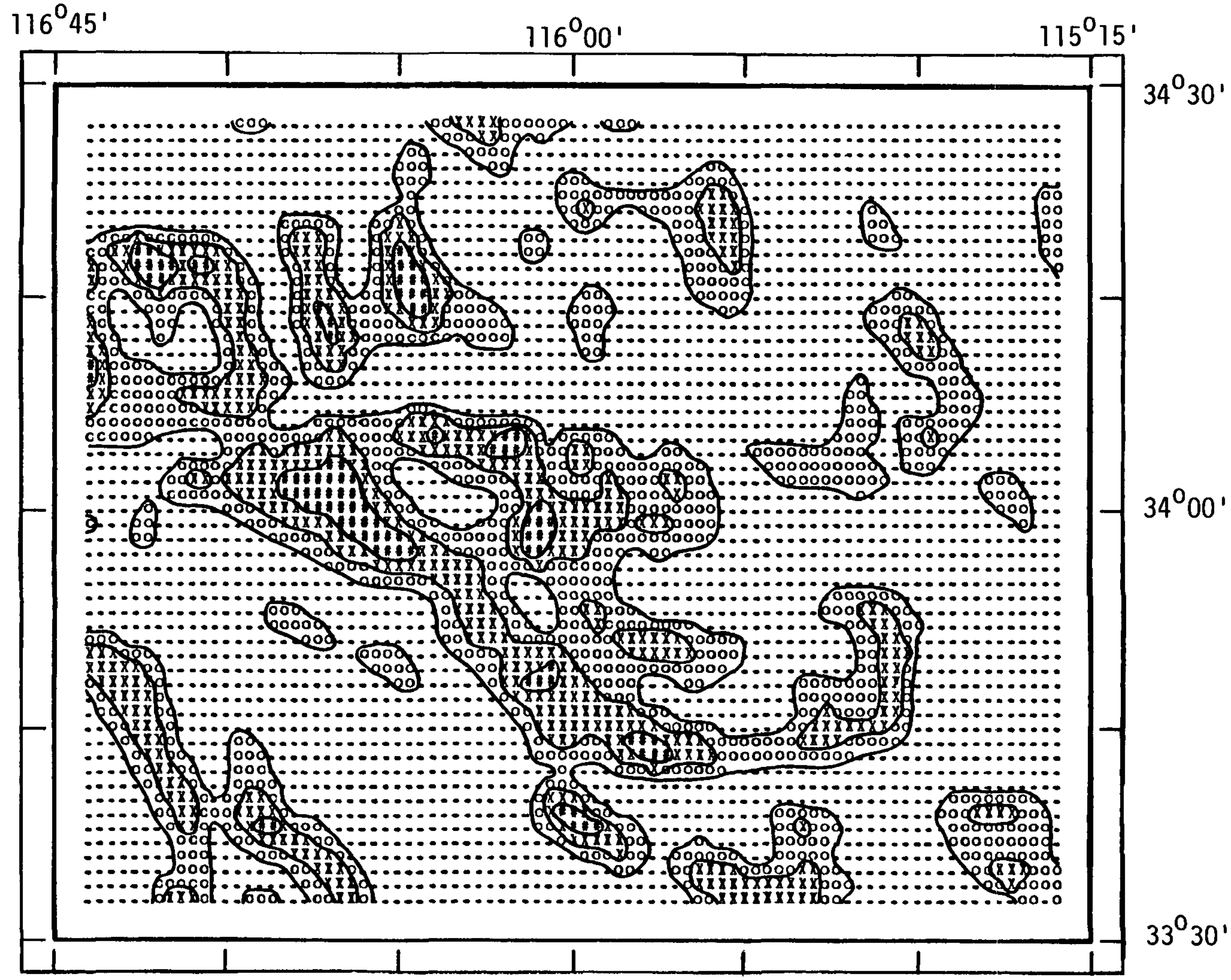


Figure 2: CONVEXITY MAP

Elevation-Relief Correlation One-Minute Pixels

+1.0 (.) +0.6 (o) +0.2 (X) -0.2 (#) -0.6

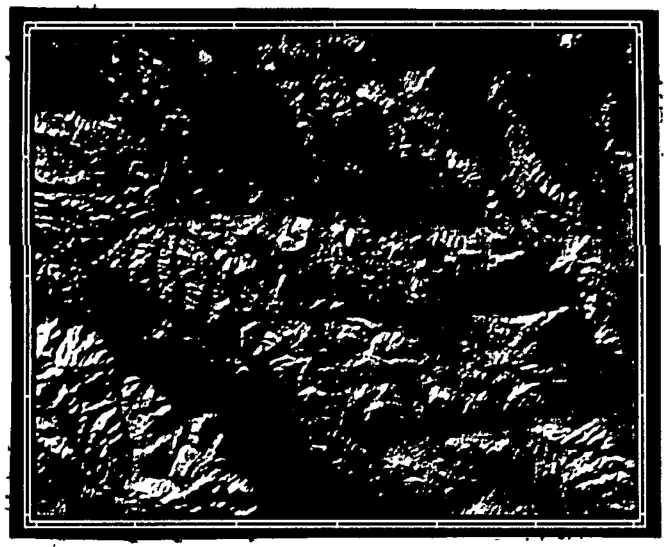


Figure 3. False-illumination topography.

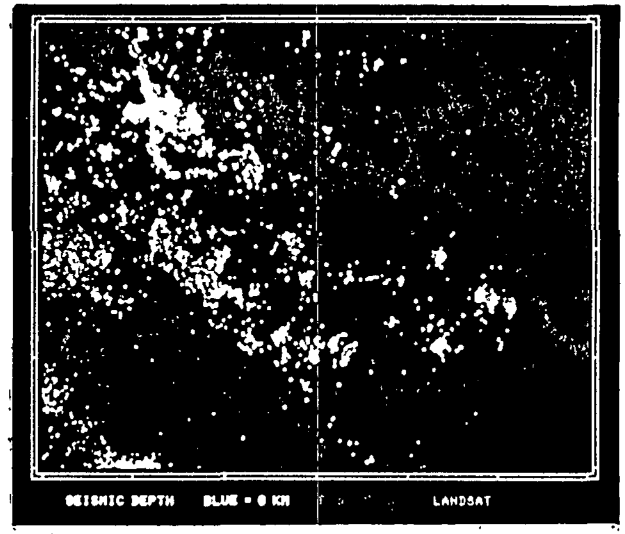


Figure 4. Earthquake epicenters (over Landsat MSS).

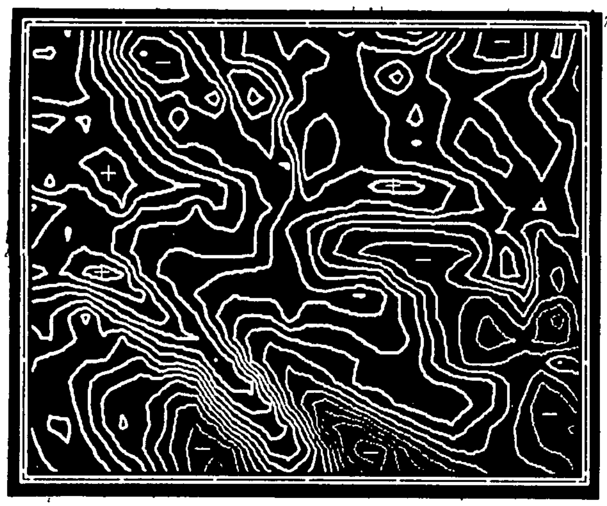


Figure 5. Bouguer gravity (5 mgal).

Figure 6. Aeromagnetics (100 gammas).

False illumination digital images (such as Figure 3) were useful in identifying regional geomorphic patterns. A slope image was created to provide a quantitative measure of this variable that is commonly correlated with zones of tectonic activity.

Gravity and Aeromagnetic Studies

Bouguer gravity data and aeromagnetic data (Figures 5 and 6) were produced both as brightness images and as contour images. Various mergers of these images with each other and with the elevation and spectral images, allowed inferences regarding major subsurface crustal trends (discussed below). When brightness images were combined with contour images, the pattern of data highs and lows was clearly evident (brightness image), as were the data gradients (contour image). This was significantly superior to the individual use of the images and vastly superior to the use of the original maps.

Earthquake Focus Studies

A "seismic-depth" image (Figure 4) was produced to provide a three-dimensional view of earthquake epicenters (locations), depths (color), and magnitudes (brightness). Direct comparison of this image with spectral, topographic, and geophysical images allowed us to evaluate the significance of some lineaments. The shortness of the seismic record is a limiting factor to this approach.

Aerial Photographic Mapping

An analysis of our study area, using low and high altitude aerial photography, has revealed a number of fault traces that were not previously mapped. These traces include: (1) an extension of the Johnson Valley fault southward along the eastern margin of the San Bernardino Mountains (west of Landers); (2) a continuation of the Calico fault southward to connect with an unnamed previously mapped fault (west of Deadman Lake); (3) numerous kilometer to five-kilometer long traces within the Central Mojave shear system and along the Pinto Mountain fault zone; and (4) various scattered short fault traces within and marginal to the Eastern Transverse Ranges.

Orbital Imagery Analysis

Digital processing of our orbital imagery data has resulted in the recognition of several features of possible neotectonic significance. The most intriging of these are numerous north-northwest trending lineaments that are oblique to the major northwest trending faults of the Central Mojave shear system. These features, seen on Seasat imagery, could constitute synthetic faults of the simple right shear model. Co-seismic faulting in recent years in this area has occurred on previously unmapped faults having this trend.

Some of the cross-valley Seasat lineaments do not correspond to any surficial features found in aerial photography or in the field. A cooperative effort with the Radar Imaging Team at NASA-JPL to study the occurrence of these lineaments has produced significant results (Blom et al., 1984). Radar imaging of subsurface features had only been clearly documented in one previous study. However, evidence found in Means Valley (figure 7, 34°27'N, 116°31'W) supports the presence of shallow-buried structural dihedral reflectors oriented perpendicular to the radar look direction. Some of these appear to be pediment-dike combinations, but in areas of deep alluvial cover, an alternative (perhaps neotectonic) explanation would be necessary. Evidence in support of a faulting explanation for many lineaments is the distinct correlation of their presence within the Central Mojave Shear System, and not in similar valleys (in the same imagery) outside the shear system.

Landsat MSS enhancement methods have included principal components analysis, ratio image combinations, high-pass filtering and various experimental techniques. The first two (MSS) or three (TM) principal component images have been particularly useful in the depiction of neotectonic displacements of Quaternary deposits. A remapping of the locations, extents, and ages of some faults was warrented.

Thematic mapper imagery clearly reveals the expression of the Blue Cut fault in the Holocene alluvium of Pinto Basin (figure 7, 33°55'N, 115°45'W) (Crippen and Spencer, 1984). Several previous field investigations failed to detect the fault trace, apparently due to its subtle and irregular character. Field studies guided by the TM imagery confirmed the geomorphic expression of the fault, which controls the irradiance and indirectly controls the reflectance properties of the terrain. The curvilinear fault trace is most prominently displayed in the long-wavelength reflectance (non-photographic infrared) channels. Multispectral color composite images further clarify the geomorphic features.

Two new quantitative techniques were developed during this study that will have widespread use in a variety of remote sensing applications. One is a method of band selection to maximize spectral information content in color composite displays of band data (Crippen et al., 1986). The method uses a matrix of bi-spectral correlation coefficients for an n-band image. A spectral information index, ranging from 0 to 1, is derived for each combination of three bands. The combination with the highest index is the combination with the most overall spectral information. Results show that for almost any ground cover, the 1,4,7 combination is preferable for Landsat TM reflectance data and that the true-color combination (1,2,3) is the worst.

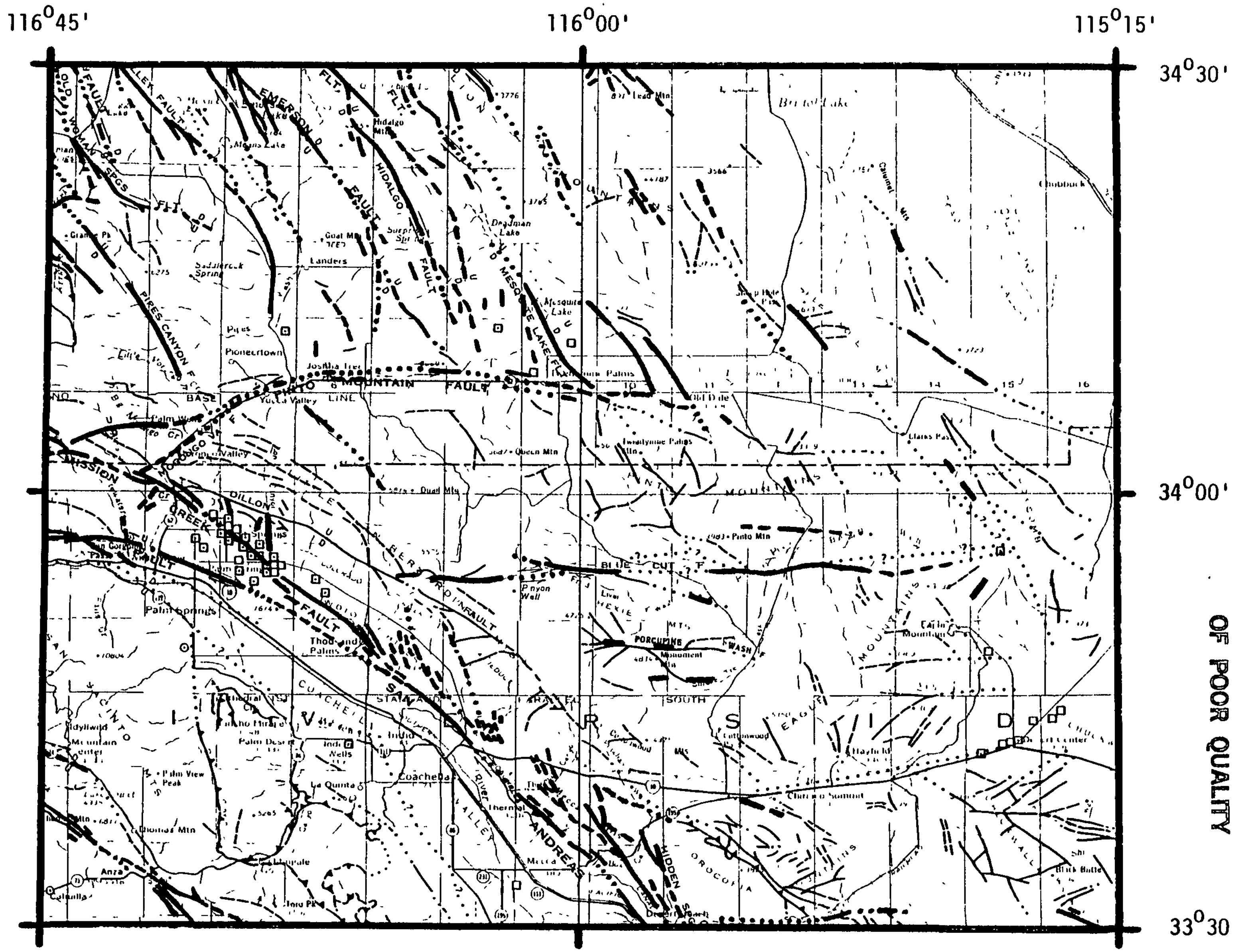
The other new technique is a method of adjusting radiance data for band ratioing. Adjustments are needed to reduce the influence of extrinsic inputs to image data, namely atmospheric path radiance and sensor calibration offsets. Ratioing was used to enhance the spectral contrast of surface materials in order to detect discontinuities of possible neotectonic origin. In simple terms, the method determines bi-spectral regression lines for homogeneous areas in rugged terrain. These lines are projected in pairs to intersection points. Ideally, the coordinates of these points must equal the measurements for zero ground radiance since that is the only condition under which spectrally different materials can have the same radiance values. Tests show that the method is successful in determining radiance correction values that result in maximum removal of the topographic effect in ratio images. The method has several advantages over other data adjustment techniques (Crippen, 1986).

Merged Data Analyses

Several combinations of the GIS data sets were used in order to evaluate geologic and geophysical features. This was especially useful for comparing the spatial patterns of surficial features (lineaments, elevation, slope, tonal anomalies) with features that are more indicative of subsurface characteristics (geomagnetic and gravity anomalies, earthquake foci).

Tectonics Summary

Southern California may be the most complex continental crustal region in North America. Recent geophysical studies have led to the development of new neotectonic models, most of which include partial decoupling (on detachment faults) within the crust. Deformation in the upper crust here consists primarily of brittle fracturing, probably driven by ductile flow (with small-scale convection) below the detachment surface. Our study has served primarily to define the character and extent of surface manifestations of recent tectonic activity so as to place constraints upon various components of those models.



Current revision of California fault map (Jennings, 1975) for study area.
Wide lines represent faults showing Quaternary displacement.

Figure 7

Fault traces mapped within the Central Mojave shear system appear to define a southward bending of the southeasterly trending system within the western half of the study area. Most of the offsets in the shear system are believed to be largely right-lateral. Vertical components of slip are inconsistent although up-on-the-east dominates in the southern region as the western blocks sag and the eastern blocks compress with the termination of the right-lateral shear system against the Pinto Mountain fault. Figure 7 displays our current update of the locations of faults of known or inferred Quaternary movement throughout the study area.

New evidence of faulting within and marginal to the Eastern Transverse Ranges has also been found. Additional traces of the Blue Cut and Pinto Mountain faults were mapped (discussed above). Also, evidence of minor faulting was found at the eastern end of the Transverse Ranges at wide angles to the east-west trends of the active faults within the ranges. This may be significant. The central and eastern Mojave Desert are known to differ in several geophysical properties (compression/extension, heat flow, vertical displacements). Their boundary extends south from the eastern end of the Garlock fault to the eastern end of the Transverse Ranges. As neotectonic models are further developed, our evidence of on-going faulting activity here may be significant in understanding the surfical manifestations of crustal deformation along this important geophysical boundary.

Seismic activity occurs primarily in the western half of the study area. Deep earthquakes are limited (in the seismic record) to the San Jacinto fault and the San Gorgonio Pass segment of the San Andreas fault. Activity occurs as far east as the eastern end of the Transverse Ranges and in the easternmost Central Mojave Desert, but not further east. This is generally consistent with the pattern of recent faulting.

The gravity and aeromagnetic images indicate crustal trends in a generally northwest-southeast pattern, even across the Transverse Ranges. Seismic studies have suggested that the Transverse Ranges are rootless and bounded on their base by a detachment surface. The patterns seen in these two images tend to support that contention.

Conclusion

Several new details regarding the surficial patterns of neotectonic activity of the Eastern Transverse Ranges and vicinity have been discovered. Additionally a number of data display and analysis techniques have been developed.

These findings will be useful both in the continued development of neotectonic models for Southern California and for the future application of remote sensing methodologies elsewhere.

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Bibliographic Record

Abstract of presentation supported in part by NASA funding of technique development:

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Journal article on research initiated in this project and supported in part by NASA funding:

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Abstract of research review presentation at NASA Geodynamics Conference:

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Crippen, Robert E., 1986, The Regression Intersection Method of adjusting image data for band ratioing: *Photogrammetric Engineering and Remote Sensing*, submitted.

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Crippen, Robert E., 1986, The Regression Intersection Method of adjusting image data for band ratioing: ERIM Fifth Thematic Conference, Remote Sensing for Exploration Geology (Reno), submitted.

Doctoral dissertaion supported largely by NASA funding:

Crippen, Robert E., 1986, Remote Sensing Investigation of Neotectonic Activity in the Eastern Transverse Ranges and Vicinity, Southern California: University of California, Santa Barbara, in preparation.

It is anticipated that additional articles, particularly regarding the neotectonic findings of this study, will be completed and submitted for publication during the next several months.