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PAUL D. LOWMAN, JR.

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November 1974

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ABSTRACT

This paper presents results of three early applications of imagery from the NASA Earth Resources Technology Satellite (ERTS-1) to geologic studies in California. In the Coast Ranges near Monterey Bay, numerous linear drainage features possibly indicating unmapped fracture zones were mapped within one week after launch of the satellite. A similar study of the Sierra Nevada near Lake Tahoe revealed many drainage features probably formed along unmapped joint or faults in granitic rocks. The third study, in the Peninsular Ranges, confirmed existence of several major faults not shown on published maps. One of these, in the Sawtooth Range, crosses the Elsinore fault without lateral offset; associated Mid-Cretaceous structures have also been traced continuously across the fault without offset. It therefore appears that displacement along the Elsinore fault has been primarily of a dip-slip nature, at least in this area, despite evidence for lateral displacement elsewhere.

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INTRODUCTION

The NASA Earth Resources Technology Satellite (ERTS-1) was launched on July 23, 1972, and began returning high-quality images from both the Return Beam Vidicon cameras and the Multispectral Scanner within two days. California was one of the first states to be extensively covered by this imagery, chiefly because of the generally cloud-free summer weather. Consequently, the first geologic studies with ERTS imagery were done on California pictures. These studies were necessarily of a reconnaissance nature, with little or no field checking, and have since been far surpassed by the work of various ERTS investigators, such as Bechtold, et al (1973), Liggett, et al (1974), and Rich and Steele (1974). However, they are of value as demonstrations of the geologic value of ERTS-1, both in structural research and in various applied fields.

This paper was originally written at the invitation of the U.S. Geological Survey for a collection of ERTS reports, but had to be omitted because of space limitations and publication deadlines. It was intended primarily for non-geologists desiring examples of the geologic use of ERTS imagery; more technical accounts of these studies are in preparation for publication elsewhere.

MONTEREY BAY AND ADJACENT COAST RANGES

This picture (Fig. 1) is of interest for several reasons. Although reproduced here in black-and-white, it was used to make the first color composite produced from ERTS images, having been transmitted only two days after launch. Furthermore, it is even now one of the best geological pictures yet returned by ERTS-1, since it shows the central San Andreas fault and many related compressional features extremely well. The accompanying sketch map (Fig. 2) was produced one week after launch of the satellite, and was the first map of any sort produced from ERTS pictures.

The picture covers parts of three major physiographic provinces of California, from southwest to northeast: the Coast Ranges, Great Valley, and

Sierra Nevada (foothills). This discussion will concentrate on the Coast Ranges, since they occupy most of the area covered.

The Coast Ranges in this area have two strongly contrasting geologic terranes (Page, 1966). The Diablo Range is a broad anticline composed largely of the Franciscan Formation, a complex assemblage of sandstones (graywackes), volcanic and metamorphic rocks, and intrusions of serpentinite, all intensely folded and faulted. The Franciscan Formation is generally thought to represent a former eugeosyncline, or depositional basin with associated volcanic areas, located at the former edge of the continent (see Bailey, et al, 1964, for a comprehensive discussion of the Franciscan). In plate tectonic theory, the Franciscan assemblage is considered to mark the former intersection of an actively spreading oceanic plate and a continental plate, overlying a subduction zone. West of the San Andreas fault, in the Santa Lucia, Gabilan, and Santa Cruz Ranges, the rocks are very different. Collectively labeled the "Salinian block," they consist of granitic igeous rocks and high-grade metamorphic rocks intruded by the granites. The metamorphic rocks include marbles and quartzites (Compton, 1966), and are probably former miogeosynclinal rocks, not metamorphosed Franciscan types. In lithology, structure, and age, they resemble rocks of the southern Sierra Nevada. Many geologists (e.g., Dibblee, 1966) feel that these two contrasting lithologic assemblages were once widely separated, the Salinian block forming part of the southern Sierra Nevada, and that cumulative horizontal movement of several hundred miles along the San Andreas fault has brought them together. This theory is controversial; ERTS images may eventually throw some light on the problem.

The first use to which this ERTS picture was actually put was a simple comparison with the geologic map of California (Fig. 3), to see how many of the structures visible on the picture were shown on the map. The San Andreas fault has of course been well-mapped, as have the folds at the lower right; the latter are strong evidence for compression caused by the right-lateral movement along the San Andreas (Dibblee, 1966). However, there are a number of drainage anomalies in the Coast Ranges, such as unusually straight valleys, or valleys with sharp, angular deflections. If other geologic explanations can be eliminated by inspection of geologic maps, features of this kind are generally interpreted by photogeologists as the result of preferential erosion along fractures - faults or joints. Many of these drainage features have no obvious explanation except fracture control, and were therefore mapped as suspected faults or joints with the provisional term "photo lineament". No field checking was possible in the time available, and it is quite possible that some have other explanations. However, if even a few of them turn out to be faults, it will demonstrate the value of ERTS imagery in correcting geologic maps. The Geologic Map of California is published at a scale of 1:250,000, and should in principle show about four times as much structural detail as the ERTS picture with a scale of 1:1,000,000 from which the map presented here was drawn. We see instead that the ERTS picture shows more detail.

Accurate structural maps are not simply a matter of scientific interest, especially in California. Faults may present severe engineering problems in construction of tunnels, roads, dams, and buildings, since the crushed rock along them is especially susceptible to cave-ins or landslides (Radbruch and Crowther, 1973). Active faults can be direct hazards, either by creep or by sudden earthquake-generating slippage. On the beneficial side, they may be the only aquifers in impermeable rocks such as granite, and many ore deposits are mineralized faults (although there is no good reason to expect mineralization along the fractures mapped in the Coast Ranges from the ERTS picture).

As mentioned earlier, this map was finished one week after the actual launch of ERTS-1; considering that it was done by a geologist with little first-hand knowledge of the area involved, the great savings in time possible with ERTS imagery are apparent. Speed in mapping geologic features millions of years old may seem at first glance unnecessary. However, in terms of a geologist's time, the situation is quite different; several years may be saved in regional mapping projects. Furthermore, the maps become available that much sooner, an important point in rapidly-developing areas such as the San Francisco Peninsula and the Monterey Bay region.

SIERRA NEVADA

Another early ERTS-1 picture of California (Fig. 4), taken on the same day as the Monterey Bay one, was used for a similar geologic analysis (Fig. 5) several weeks later (Lowman, 1973). This picture covers part of the northern Sierra Nevada, including in addition part of the Great Valley and the western corner of Nevada. The western foothills of the Sierra Nevada shown here are part of the Mother Lode Belt, whose gold deposits stimulated the explosive settlement of California from 1848 on.

Geologically, the Sierra Nevada can be described as a huge crustal block, largely granitic rocks of a batholith with the same name, uplifted along faults on its east side and tilted to the west (Shelton, 1966). Relief is not well displayed in this picture, which like all ERTS pictures was taken vertically, but the general structure is visible. The strong influence of altitude on vegetation, due to increasing precipitation with height, is evident; the lower areas are generally dry and relatively barren, except for those under irrigation, in contrast to the forested mountains.

The ERTS picture was compared with appropriate sheets of the Geologic Map of California (Fig. 6), with the objective, as for the Monterey Bay picture, of finding out how many mapped structural features were visible on the picture. Examination of the ERTS picture revealed at once a number of unusually straight valleys in the Sierra, generally trending southwest-northeast (with streams flowing southwest). Much of this drainage pattern is "consequent," i.e., resulting simply from the slope of the land surface (Bateman and Wahrhaftig (1966)). However, many of these unusually straight valleys, especially in the granitic part of the Sierra, may be fracture-controlled, and have been mapped accordingly. Two kinds of fracture are possible: joints, essentially tension cracks, with no movement along the fracture; and faults, with movement in some direction along the fracture. Joints probably account for most of the linear drainage features, according to Bateman and Wahrhaftig (1966). However, if even a few are unmapped faults, the value of ERTS in supplementing conventional geologic mapping methods will again be demonstrated.

It may be wondered why geologic maps published fairly recently should be so incomplete. The answer is that the 1:250,000 scale Geologic Map of California is not a primary map, but a compilation of previously-published maps done in smaller areas. The source diagram for the sheet presented here shows that much of the mapping on which it is based was done in the 1890s; thus even a map with a nominal date of 1958 can be fundamentally out of date.

PENINSULAR RANGES

The third area studied with early ERTS images is in extreme southern California: the Peninsular Ranges, in San Diego County (Fig. 7). This area had been photographed before from Gemini and Apollo spacecraft, and several unmapped fracture zones had been discovered (Lowman, 1969, 1971). The ERTS picture (Fig. 8) provided stimulus for further work in this area. Before summarizing it, let us examine the regional geology (Fig. 9); good descriptions are provided by Jahns (1954) and Oakeshott (1971).

The Salton Sea is of course the most conspicuous feature. Lying below sea level, it was formed in 1902 by accidental flooding from breached irrigation canals carrying Colorado River water into what was then called the Salton sink. Structurally, this valley is called the Salton Trough and is clearly of structural rather than erosional origin, having been formed largely by down-faulting. It has several hot springs and young volcanic plugs, and is underlain by numerous active faults. The trough has been interpreted as a continental area under which sea-floor spreading is taking place (Elders, et al, 1972); the Gulf of California in this concept is the result of this process in a more advanced state of development. The Peninsular Ranges separate the Salton Trough from the Pacific

Ocean (Fig. 7). They are structurally and lithologically the southern extension of the Sierra Nevada, and can also be considered a west-dipping block bounded by faults along its east side. The rocks, like those of the Sierra Nevada, are chiefly Mesozoic granitic and gabbroic igneous rocks occurring in a series of intrusions collectively making up the southern California batholiths. There are also subordinate metamorphic rocks and post-batholithic sedimentary and volcanic rocks.

Many linear drainage features are visible in the Peninsular Ranges on the ERTS picture; limited field reconnaissance has shown these to have several origins. Foliation in pre-batholithic metamorphic rocks in the Laguna Mountains and elsewhere accounts for some parallel ridges and valleys; these are shown on the map with a solid foliation symbol. Erosional ridges and valleys are also controlled by flow structure and subsequent jointing in the igneous rocks. In the vicinity of Campo, for example, a series of concentric valleys has been found to follow the orientation of metamorphic inclusions and even individual phenocrysts (crystals) in granite. This type of feature, also found near Santa Ysabel Creek, is shown with an open foliation symbol.

Except for a few valleys, such as that west of Campo, controlled by known faults (Weber, 1963), the most conspicuous drainage feature west of the Elsinore fault is a family of northeast-trending linear valleys. These include the valley occupied by the San Diego River and several others roughly parallel to it. It is hard to tell with certainty whether these valleys are controlled by faults or joints because of the scarcity of good lithologic contacts that might show offset. However, some show definite evidence of movement, such as crushed zones and slickensides, and they have been tentatively mapped as faults (S.D.R.F. stands for San Diego River fault and S.R.F. for Sawtooth Range fault). Merifield and Lamar (1974), working with ERTS and Skylab imagery, have interpreted several of the same lineaments as faults, although they prefer the term "San Diego lineament" to "fault" pending field confirmation of faulting. They also interpret the lineament interpreted here as the northeast end of the San Diego fault as a separate fracture, the San Ysidro fault. Regardless of these differing interpretations, it is clear that here, as in central California, orbital images have much to contribute to geologic mapping.

We come now to another application of the ERTS picture, this time to a specific tectonic problem: the nature of displacement on the Elsinore fault. This fault, named after Lake Elsinore (Fig. 7), is undoubtedly one of the San Andreas family. As mentioned previously, the San Andreas fault itself is known to have considerable horizontal cumulative displacement, although estimates range from 350 miles (Dibblee, 1966) to only "a few tens of kilometers" (Baird, et al, 1974). The San Jacinto fault (see map) has been shown by Sharp (1967) to have undergone about 15 miles of cumulative horizontal displacement. However, the amount of displacement on the Elsinore fault has never been determined, although because of its obvious close relation to other faults of the San Andreas family, most authorities consider a figure of several miles likely. The Whittier fault, which is probably a northern branch of the Elsinore (Gray, 1961), appears to have had about 20 miles of cumulative horizontal movement (Lamar, 1961).

The ERTS picture suggests that, contrary to most opinion, there has been little or no horizontal displacement along the Elsinore fault, at least in the area covered by the picture. This is inferred from the fact that at least three of the previously-unmapped fractures in the Peninsular Ranges cross the still-active Elsinore fault without visible lateral offset (the ground resolution being about 80 meters). The intersection of one of these, the Sawtooth Range fault, with the Elsinore fault has been examined in some detail. This intersection appears to be a ridge connecting the opposite sides of the Elsinore fault. Since the Elsinore is active (Oakeshott, 1971), this alone raises some doubt as to the reality of major horizontal offset. But more important is the fact that, when examined in detail, the Mid-Cretaceous structure in the igneous and metamorphic complex making up the ridge can be traced continuously across the Elsinore fault. Furthermore, there is no particular difference in lithology across the fault, in contrast to the situation along other faults of the San Andreas family, which generally bring together strongly contrasting rock types (Dibblee, 1966).

This surprising discovery requires further investigation, especially since it does not invalidate the good evidence for lateral displacement elsewhere along the Elsinore fault. In Banner Canyon, just a few miles northwest of the Sawtooth Range, there are good stream offsets, and the evidence for major displacement along the Whittier fault found by Lamar has been mentioned before. But the work discussed here demonstrates very well how ERTS imagery can pinpoint small areas crucial to the understanding of a regional structural problem.

SUMMARY

California is located on the boundary between two major crustal plates, a boundary marked by seismic activity, active orogeny, landslides, subsidence, and volcanic activity - but also by rich deposits of oil, gas, and scores of economically usable minerals. Geology is thus a vital applied science in the state, and accurate geologic mapping is absolutely necessary for many purposes. It is quite clear that ERTS-1 and its successors will make valuable contributions to what is already one of the best state geologic mapping programs in the country.

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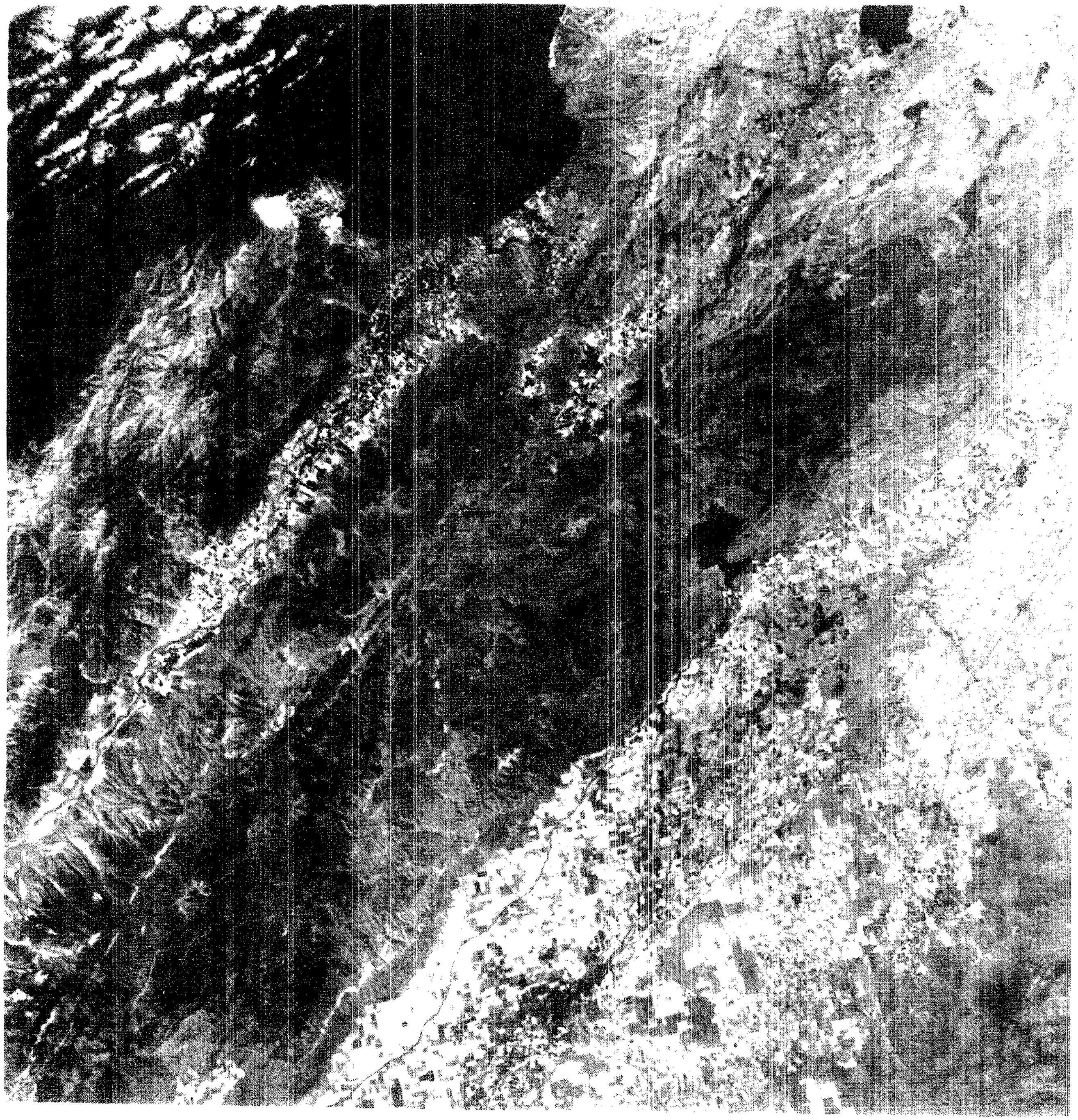
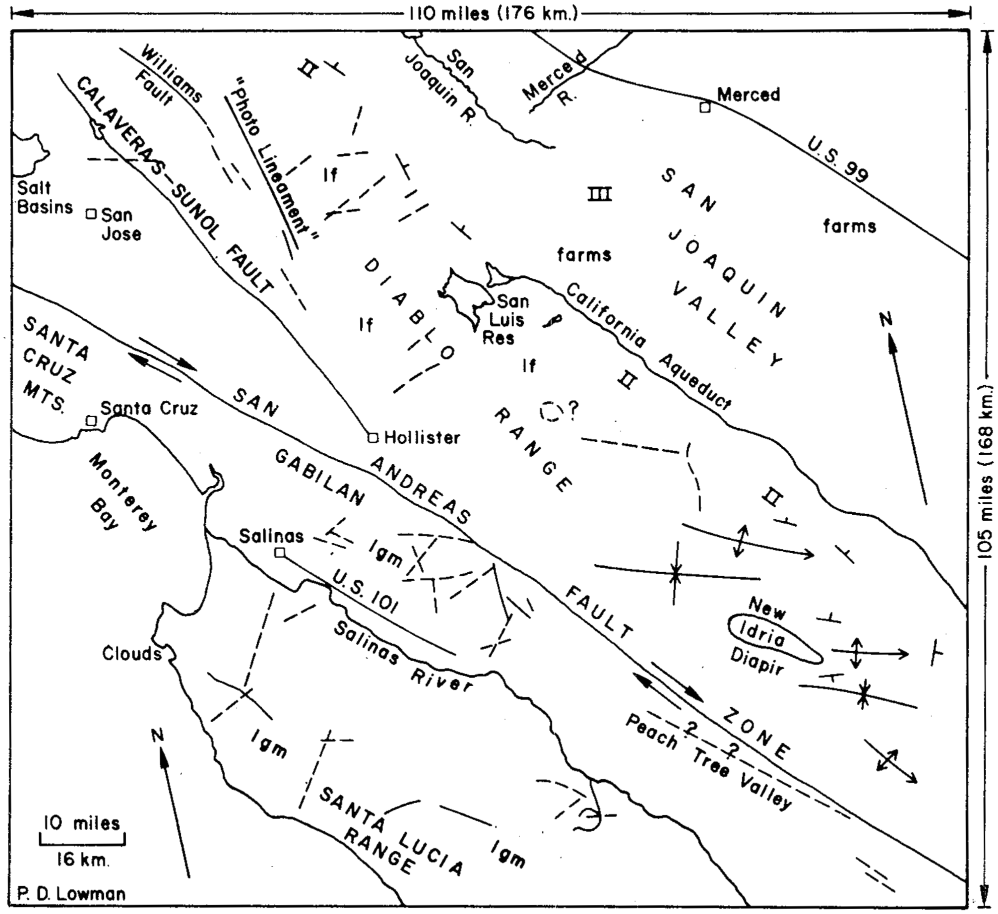


Figure 1. ERTS-1 Multispectral Scanner view of Monterey Bay and central California, Band 7 (0.8 - 1.1 micrometers; near infrared), 25 July 1972. See Fig. 2 for landmarks and geologic structure.



GEOLOGIC SKETCH MAP
CENTRAL COAST RANGES, CALIFORNIA

Legend:

Calaveras Fault (underlined)	Fault shown on 1:250,000 Geologic Map of California
------	Photo lineament (fault ?) not shown on Geologic Map of California
↕→	Plunging anticline
⨯→	Plunging syncline
┬	Attitude of strata (schematic)

Scale and orientation shown on map; principal point approximately 36°45'N, 121°10'W. Spacecraft altitude 560 stat. miles (900 km). Lithology after Page (1966); contacts not drawn:

III	Cenozoic terrestrial sediments
II	Late Mesozoic marine sediments (Great Valley sequence)
Igm	Granitic-metamorphic core complex with Cretaceous igneous intrusions
If	Franciscan core complex (Mesozoic eugeosynclinal rocks)

Paul D. Lowman Jr.
Goddard Space Flight Center
30 July 1972

Figure 2. Geologic sketch map of Fig. 1. First map of any sort drawn from ERTS images; note date (lower right).

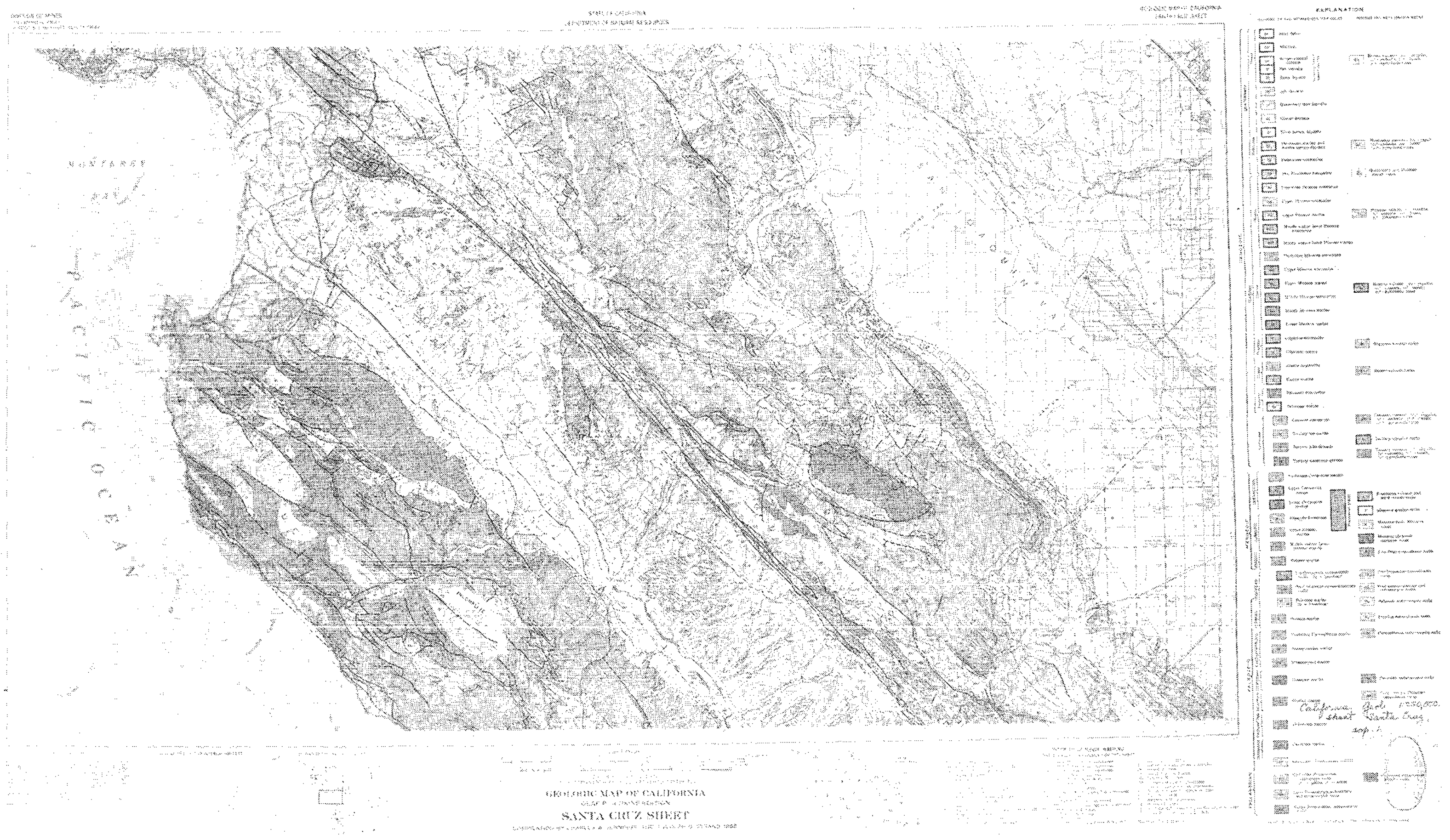


Figure 3. Portion of Geologic Map of California, Santa Cruz Sheet. Note scarcity of northeast-trending faults in Gabilan Range (left center) and other ranges.

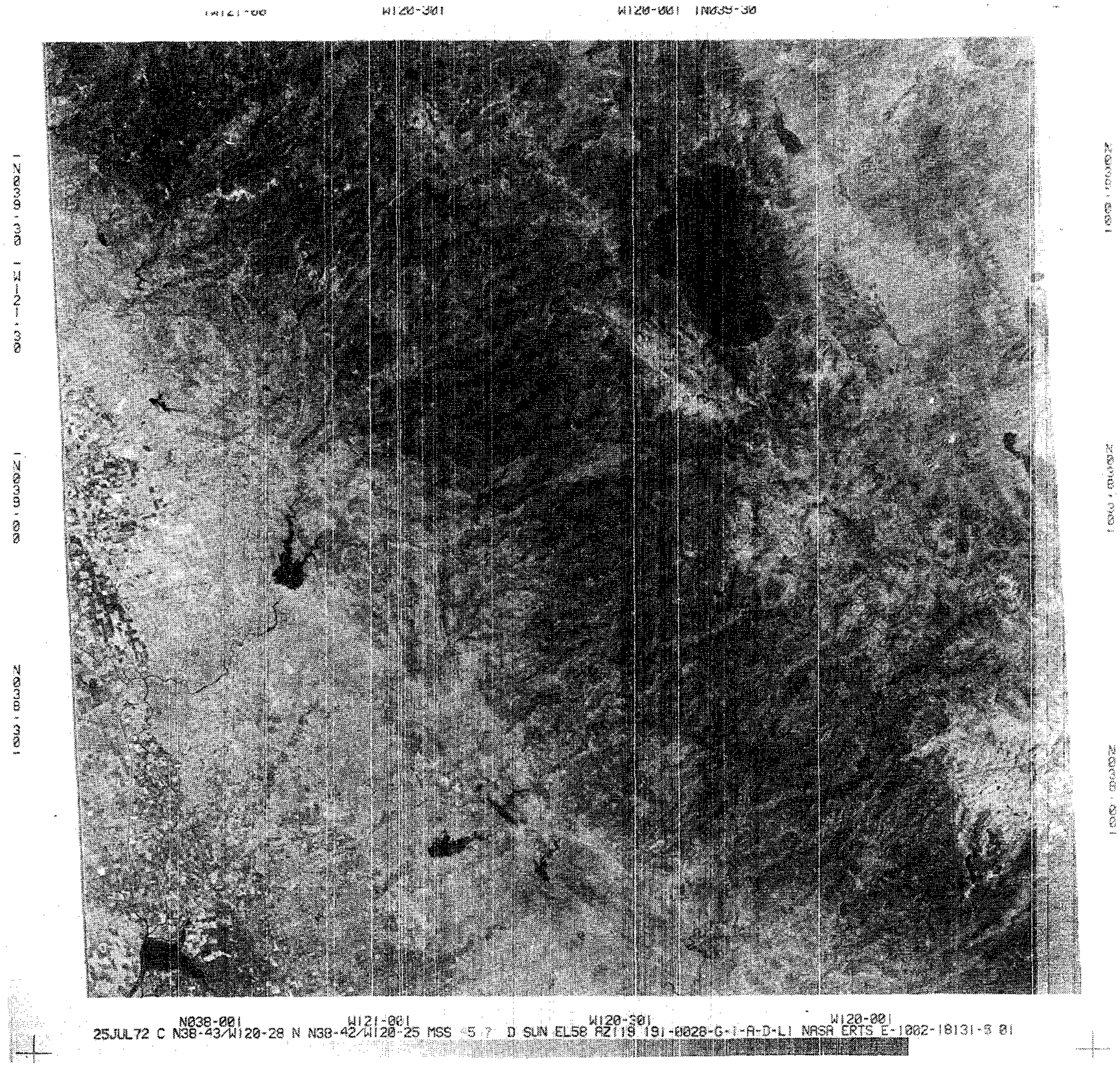


Figure 4. ERTS-1 Multispectral Scanner view of Sierra Nevada; original in color. Lake Tahoe at upper right. See Figs. 5 and 6 for landmarks.

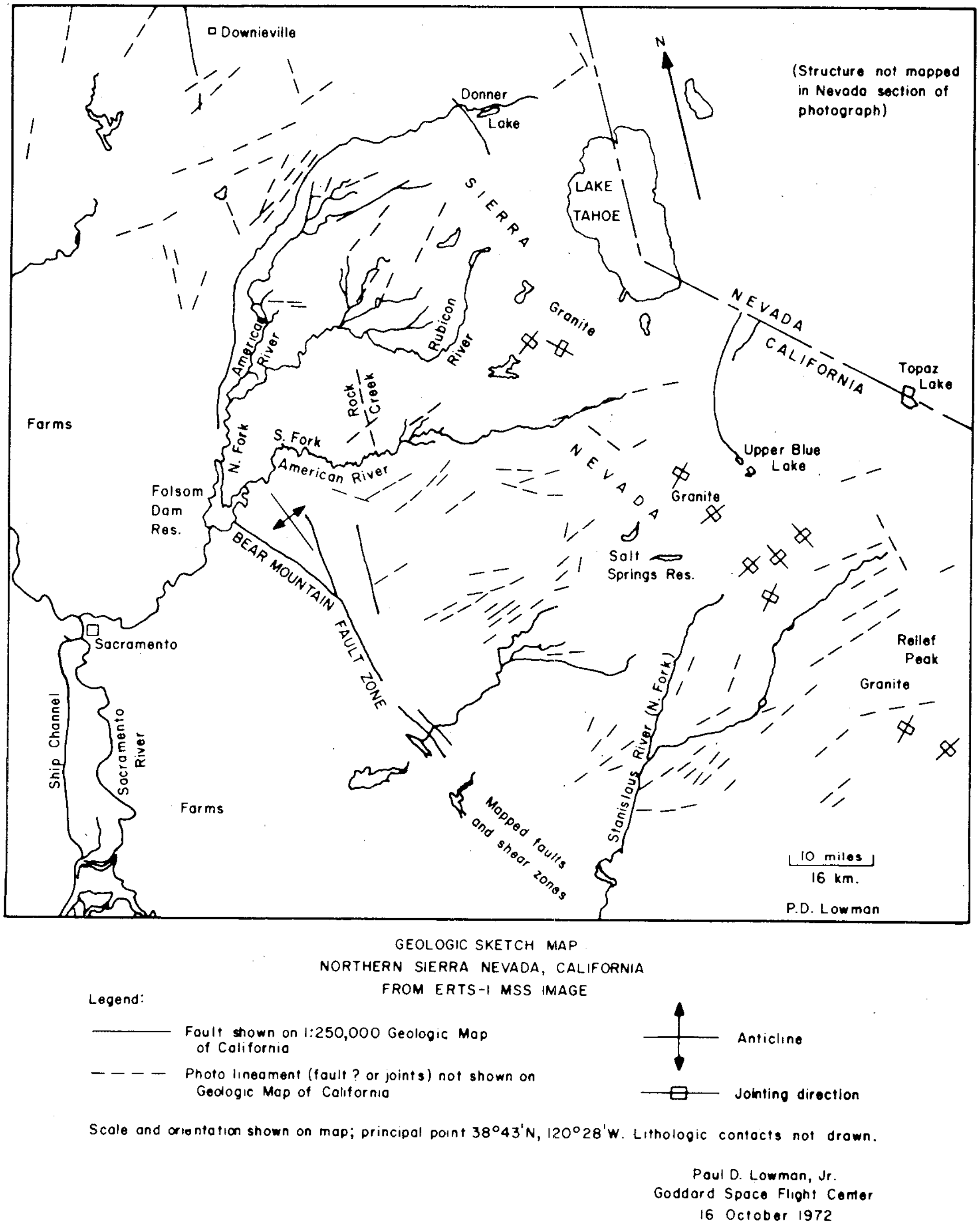


Figure 5. Geologic sketch map of Fig. 4; first published by Lowman (1973).

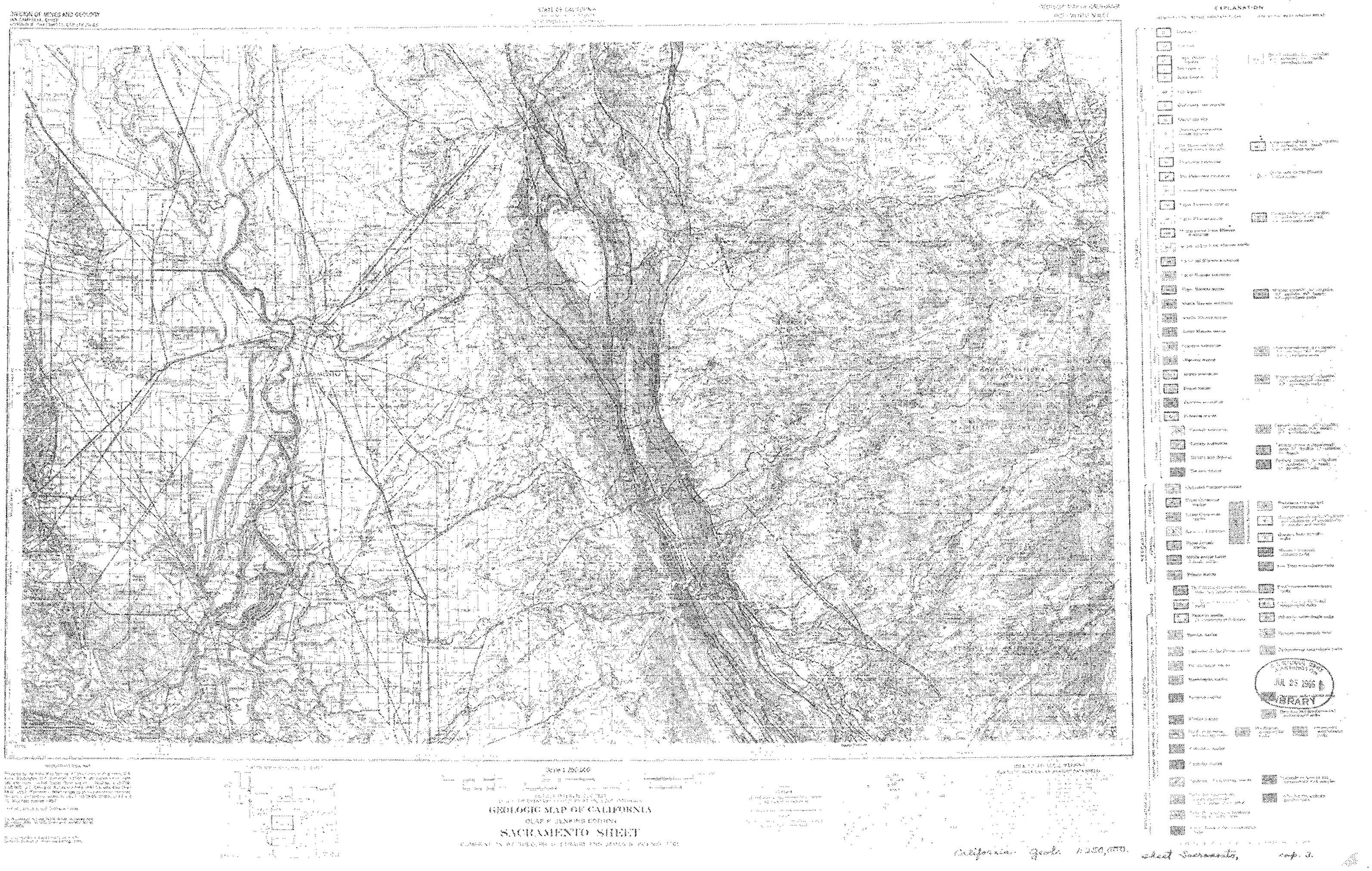
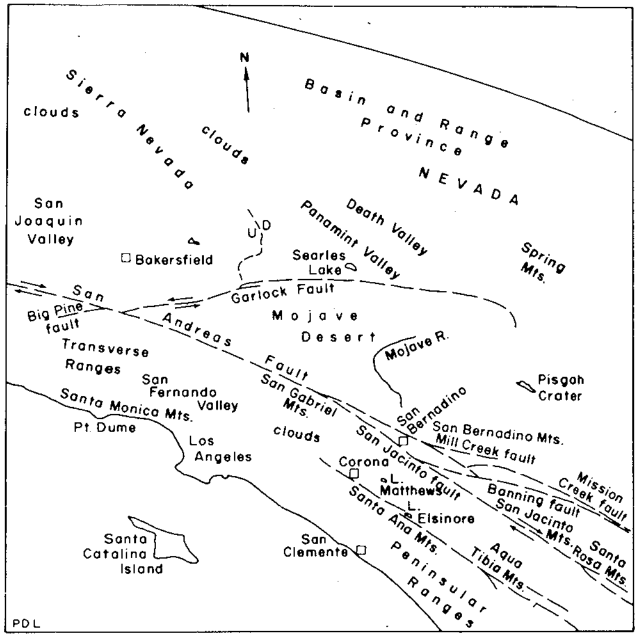


Figure 6. Portion of Geologic Map of California, Sacramento Sheet. Lake Tahoe at upper right corner. Note absence of northeast-trending faults in Sierra Nevada (right half of map).



INDEX MAP
APOLLO 7 PHOTOGRAPH AS 7-11-2022
Note: Scale variable; Bakersfield - Searles Lake distance 95 miles.

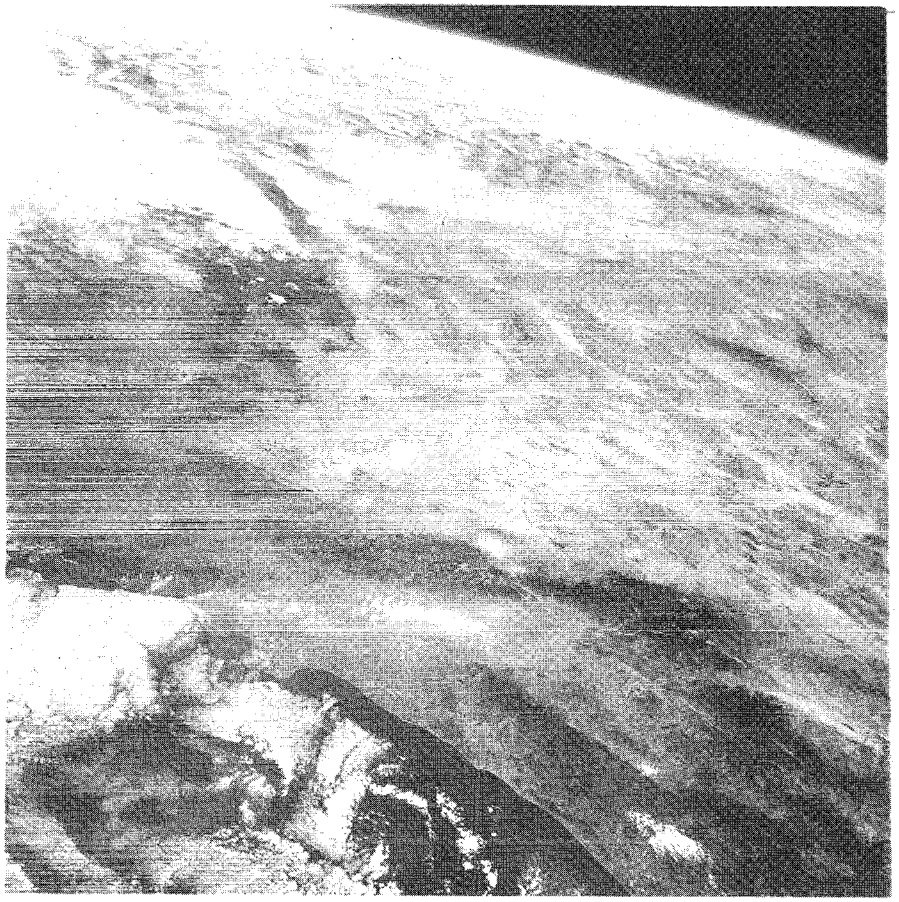


Figure 7. Oblique view of southern California from Apollo 7 (Lowman, 1972a), showing relation of Peninsular Ranges to regional structure. Elsinore fault forms northeast edge of Santa Ana Mountains and southwest edge of Agua Tibia Mts. San Diego just off picture to lower right.

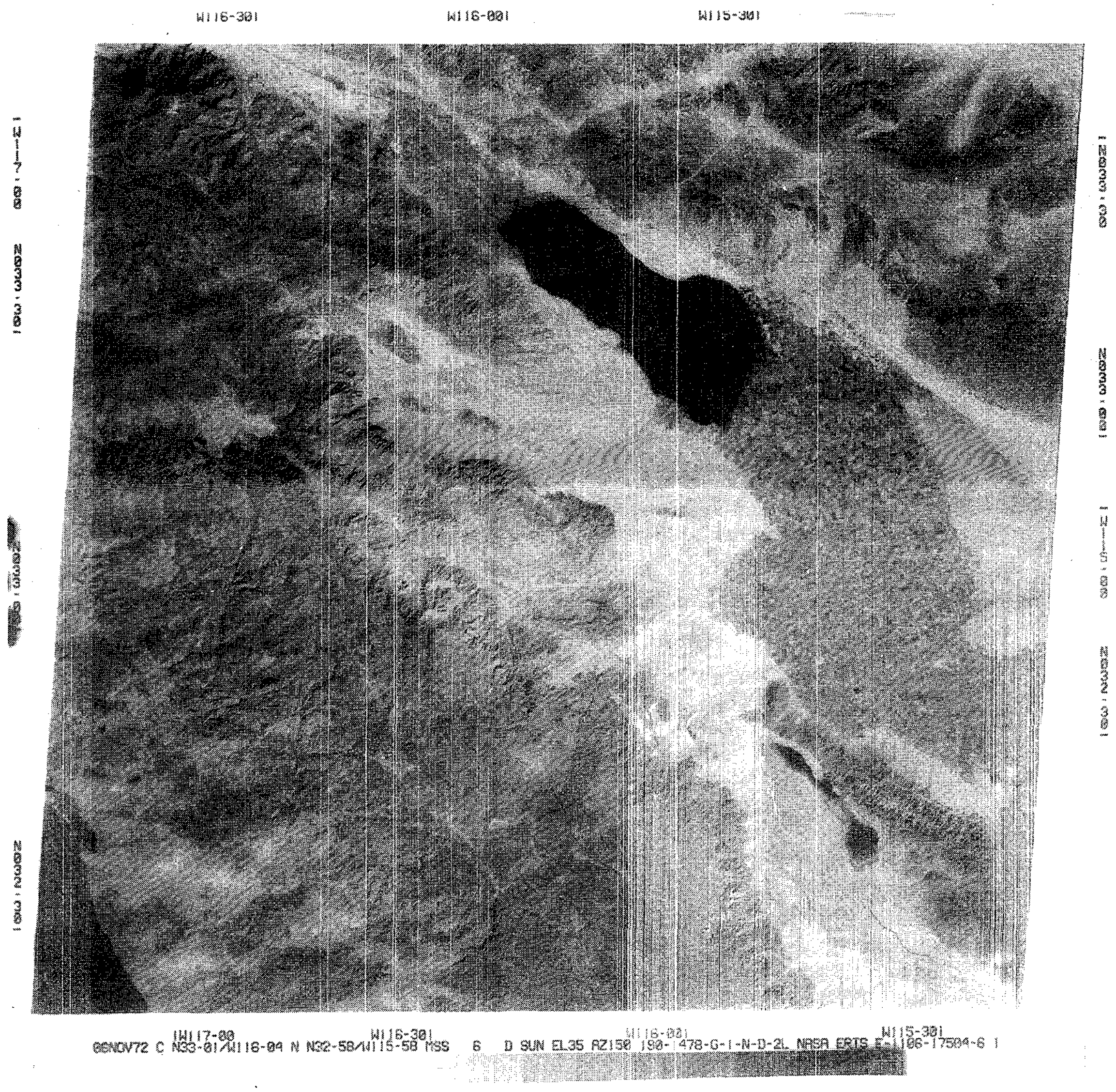
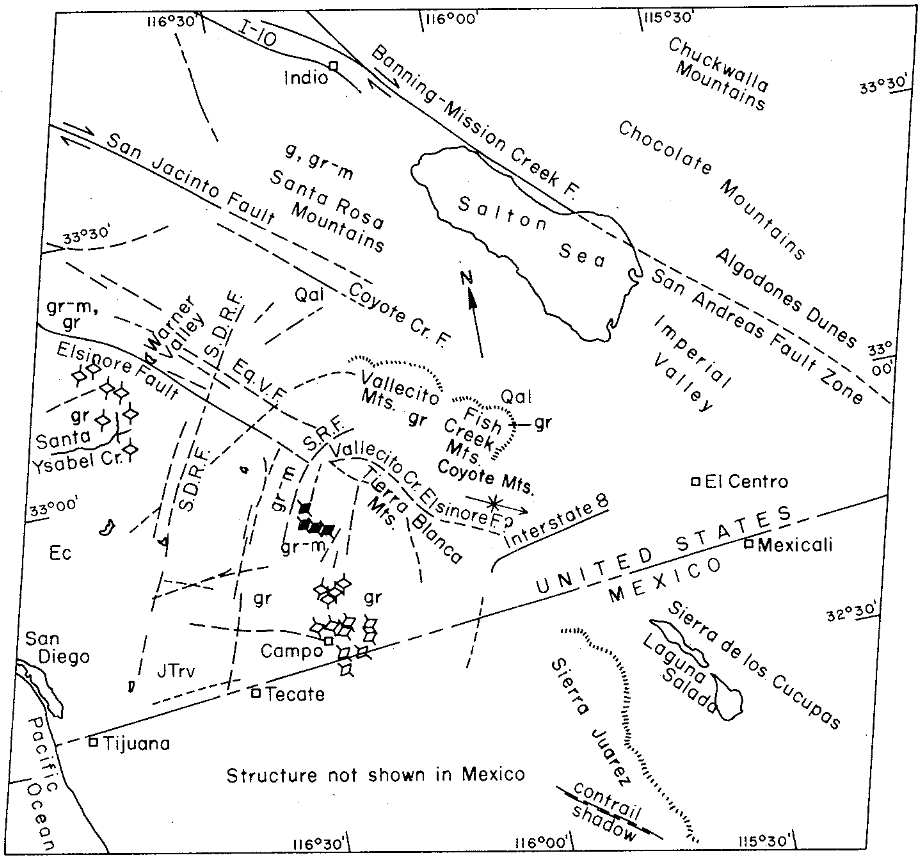


Figure 8. ERTS-1 Multispectral Scanner view of San Diego County and vicinity, Band 6 (0.7 - 0.8 micrometers); near infrared, 6 November 1972. See Fig. 9 for landmarks and geologic structure.



STRUCTURE SKETCH MAP

Peninsular Ranges, San Diego County, California

ERTS-I Image 1106-17504 (6 Nov. 72)

STRUCTURE

——— - - - - Fault (solid where confirmed, dashed where inferred or nature not certain).

—◆— Foliation in metamorphic rocks.

—◇— Flow structure in intrusive igneous rocks (inclusions, crystals, etc.).

—✳→ Plunging Syncline

LITHOLOGY*

Qal	Quaternary alluvium.
Ec	Eocene nonmarine sediments.
gr	Mesozoic granite rocks.
gr-m	Pre-Cenozoic granite and metamorphic rocks.

*Lithology from Geologic Map of California (1:250,000 sheets)

Paul D. Lowman, Jr.
Goddard Space Flight Center
October, 1973

Figure 9. Geologic sketch map of Fig. 8. Continuity of San Diego River fault across Elsinore fault not proven; Merifield and Lamar (1974) suggest no continuity.

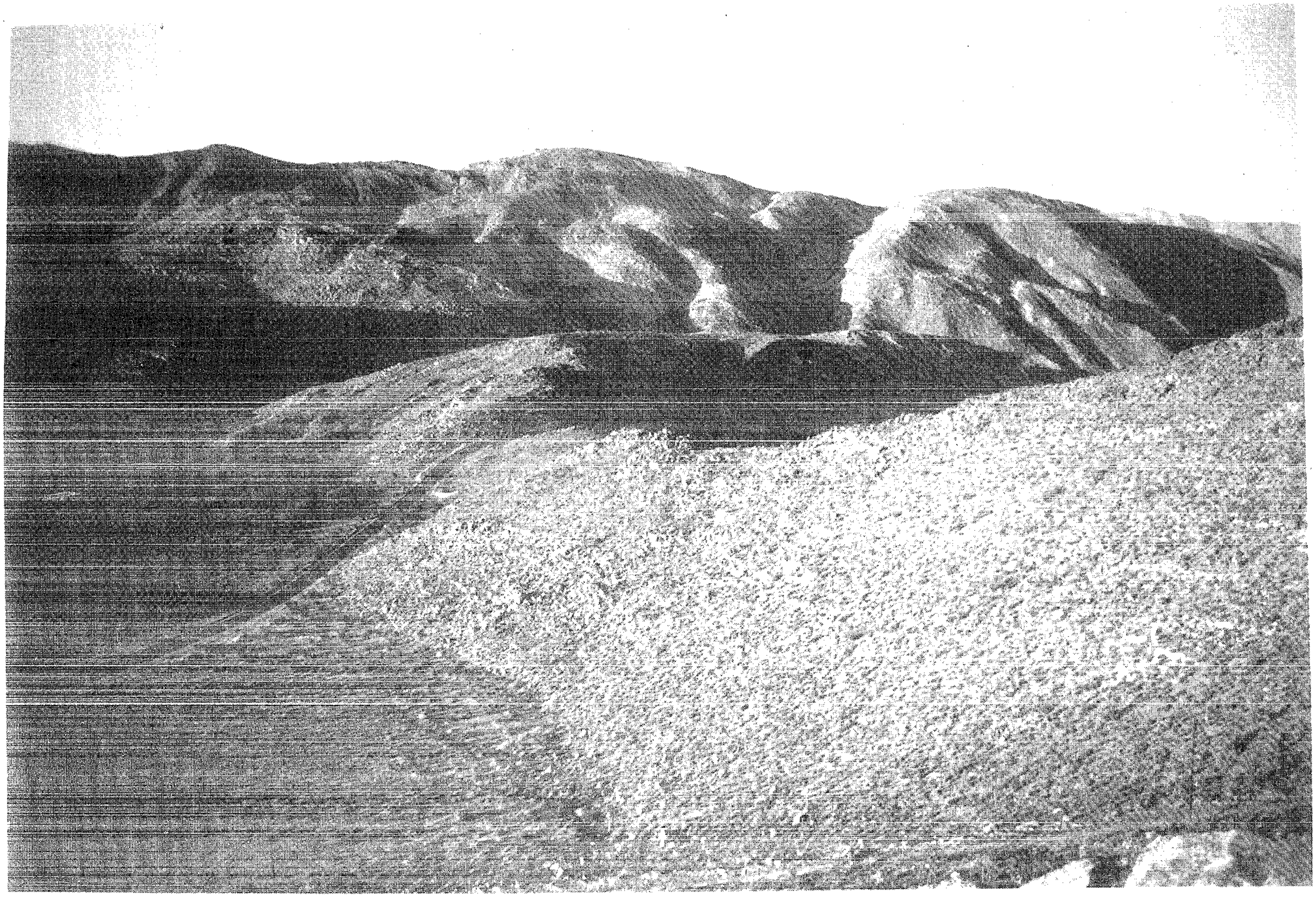


Figure 10. View to northeast along Sawtooth Range and continuing lineament (canyon on skyline at upper right). Elsinore fault intersects Sawtooth Range where county routh S2 crosses range at center; fault trends from left to right (southeast; see Fig. 9. Sawtooth Range here forms an arcuate ridge opening to the right; field reconnaissance shows this to be a southeast-plunging syncline. Elsinore fault does not disrupt syncline; structure can be traced without offset from camera site to ridge on skyline at upper right, arguing against significant lateral movement.

Figure 11. View to southeast from state route 78 five miles southeast of Julian down Banner Canyon, San Diego County, formed by erosion along Elsinore fault zone. Granite Mountain on horizon, center. Local break of Elsinore fault forms aligned terraces. One tributary canyon at left shown right-lateral offset; three others to north show similar offset.