A Comparison of Landsat MSS and TM Imagery for Interpretation of Geologic Structure

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ABSTRACT: Landsat-4 Multispectral Scanner (MSS) and Thematic Mapper (TM) images of the Death Valley region in California are compared to demonstrate the improved interpretability of geologic structures afforded by Landsat TM data. The greater spatial resolution of the Landsat TM data allows faults and folds to be interpreted more reliably; secondary features such as *en echelon* folds that cannot be resolved by MSS can be mapped with TM. Identifying *en echelon* folds associated with strike-slip faults and determining their orientation can help characterize the sense-of-strike separation. This additional information may be critical to understanding the tectonics of an area.

INTRODUCTION

THE LANDSAT THEMATIC MAPPER (TM) is an Earth resources imaging system that provides data of improved spatial resolution over the Landsat Multispectral Scanner (MSS). Landsat-4 and Landsat-5 satellites carried both instruments. Although the spatial resolution of TM data have been extensively analyzed and compared with the MSS (for example, special issues Vol. 51, No. 9, *Photogrammetric Engineering and Remote Sensing*, and vol. GE-22, no. 3, *IEEE Transactions on Geoscience and Remote Sensing*), the effect of improved spatial resolution on geologic applications of the data has not been widely reported. This paper illustrates the effect of the improved resolution of TM data on one particular geological application: mapping *en echelon* folds associated with strike-slip faults.

The greater spatial resolution of the TM coupled with its improved geometric fidelity and radiometric sensitivity allows smaller geologic surface features to be recognized on TM images compared to MSS images. One measure of spatial resolution is the size on the ground of a single measurement called the ground-projected instantaneous field-of-view. This resolution is about 79 by 79 metres for the MSS and 30 by 30 metres for the TM. TM resolution is sufficient to meet U.S. National Map Accuracy Standards at scales smaller than 1:100,000 (Welch *et al.*, 1985).

The enhanced ability to map geological structures that results from these improvements is demonstrated in a comparison of Landsat-4 MSS and TM images of the Death Valley region in California (Figure 1). The Landsat-4 scene was acquired 17 November 1982 with the sun 30 degrees above the horizon. The scene identification number, 40124-17495, refers to both the MSS and the TM images because they were acquired simultaneously. Differences in the appearance of the MSS and TM images are due primarily to differences between the instruments, because both recorded the scene at the same time, from the same satellite platform, and under the same illumination conditions. The Death Valley region was chosen for this study because of the excellent exposure of structural features there and the availability of Landsat-4 TM coverage of the area.

INTERPRETATION OF EXPOSED STRUCTURAL ELEMENTS IN THE DEATH VALLEY REGION OF CALIFORNIA

The central Death Valley Trough exhibits elements of both wrench fault and extensional fault-block structural styles. The valley is a northwest-trending half-graben between two horsts tilted to the east. Bounding normal faults on the east side of the valley dip steeply west and strike either north-northwest or northeast (Figure 2). Such multidirectional sets of normal faults are typical of an extensional fault-block structural style (Harding and Lowell, 1979). These normal faults are bounded on the north and the south by two northwest-striking wrench faults, the Furnace Creek Fault and the southern Death Valley Fault, respectively. The Death Valley Graben is believed to have been formed by extension parallel to these wrench faults (Burchfiel and Stewart, 1966; Wright *et al.*, 1974; Stewart, 1983).

The extensional fault-block and wrench fault structural styles observed in Death Valley can be distinguished using either lower resolution MSS imagery or higher resolution TM imagery. An extensional fault-block structural style is usually expressed by high-angle dip-slip faults (with a normal throw). These faults have a consistent topographic high-side and are characterized by multidirectional fault sets that form "trap-door" structures (Harding and Lowell, 1979), which are recognizable in both MSS (not shown here) and TM imagery (Figure 2, at arrow 1). In contrast, the strike-slip faults are characterized by relatively long, straight fault-line traces without a consistent topographic high-side and may occur in valleys. These faults can also be easily identified in both MSS and TM images (Figure 2, at arrow 2).

Structures associated with strike-slip faults, such as *en echelon* folds, may also be mapped on TM images, although they may be too small to be mapped on MSS images. For example, identification of the Confidence Hills in the southern Death Valley (Figure 3) as *en echelon* folding is problematic using MSS images: Although the outline of the hills suggests a fold, other features such as flatirons and topographic Vs associated with the fold cannot be discerned on MSS images, and hence the trace of the hinge surface of the fold cannot be clearly mapped. These secondary features are easily mapped on the TM image, allowing the orientation of the fold to be determined relative to the fault.

To the south, a segment of the southern Death Valley Fault zone near the Amargosa River cuts a small *en echelon* fold in Quaternary lacustrine sediments. Both structural elements are clearly depicted on the TM image (Figure 4); however, because of the low topographic relief and low tonal contrast of the fault and fold with their surroundings, neither feature is recognizable on the MSS image. In both of these examples, *en echelon* features related to strike-slip faults can be mapped using the TM image. The orientation of these features, relative to the fault, can then be used to determine the sense of strike separation along the faults (Harding, 1974). Furthermore, the presence of well-developed *en echelon* folding implies that the wrench fault is probably convergent; *en echelon* folds are poorly developed along divergent wrench faults (Wilcox *et al.*, 1973).

Available published geologic maps do not accurately depict the orientation (relative to the southern Death Valley Fault Zone) of the *en echelon* folds described in this paper (Figures 3 and 4) or these maps do not show the folds at all. Noble and Wright (1954, plate 7, approximate scale 1:281,000) map both the folds, but show them parallel (not *en echelon*) to the wrench fault. Neither fold is shown on the Trona sheet of the *Geologic Atlas of California* (Burnett and Troxel, 1962, scale 1:250,000); folds

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PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 53, No. 9, September 1987, pp. 1245–1249

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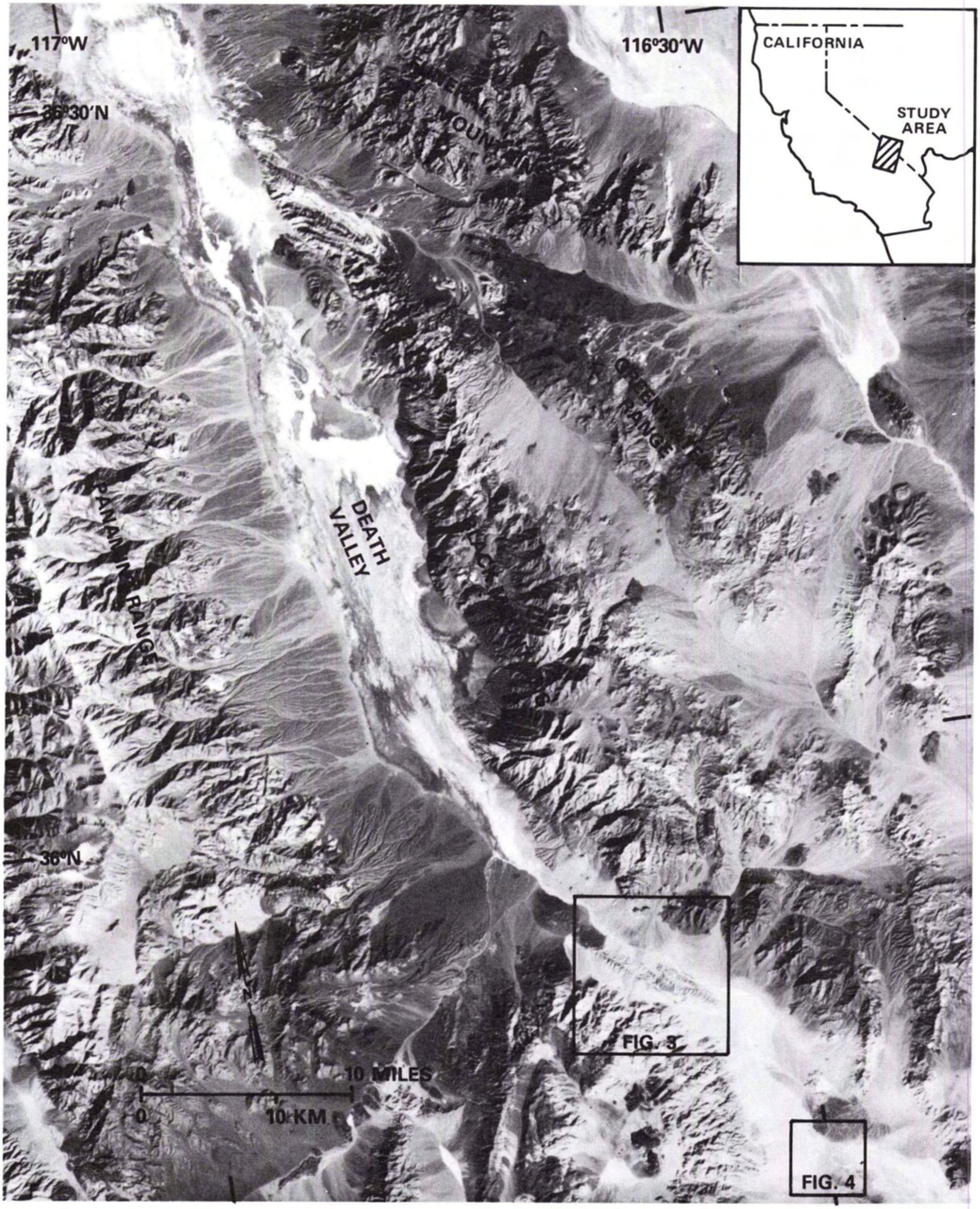

FIG. 1. Landsat TM band-pass 4 image of the Death Valley study area in California showing the locations of Figures 3 and 4. This scene, 40124-17495, was acquired on 17 November 1982 with the sun 30 degrees above the horizon.

were not shown on early editions of the *Geologic Atlas of California* and, although the Trona sheet is being revised to show folds, the new edition was not available as of this writing.

Thus, the greater spatial resolution of the TM data allows faults and folds to be mapped more reliably; secondary structures associated with strike-slip faults that are not recognizable on MSS images can be mapped on TM images. Furthermore, these structures may not be accurately portrayed on available

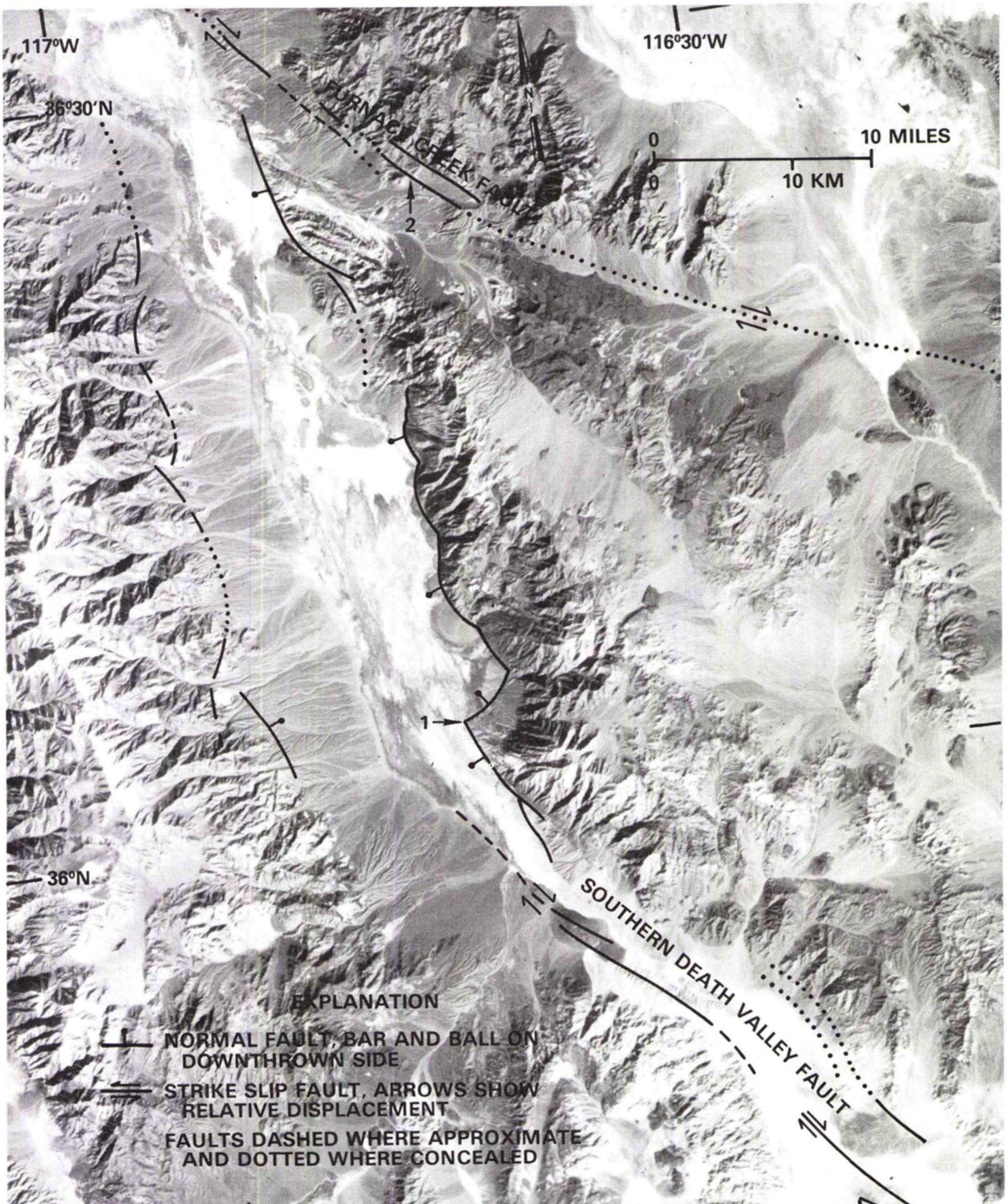

FIG. 2. Landsat TM band-pass 4 image of the Death Valley study area (the same as Figure 1) annotated with selected, major faults (modified from Wright (1976)) that can be recognized on the image. Note that normal faults at arrow 1 are characteristically multidirectional and that the upthrown fault block is consistently high topographically. In contrast, both sides of the Furnace Creek strike-slip fault occur in a valley near arrow 2, and the fault is relatively long and straight.

published geologic maps. The nature and orientation of these secondary structures can provide valuable information for understanding the tectonics of an area.

ACKNOWLEDGMENTS

The writer is indebted to Exxon Production Research Company for permission to publish this investigation. Paul Butler

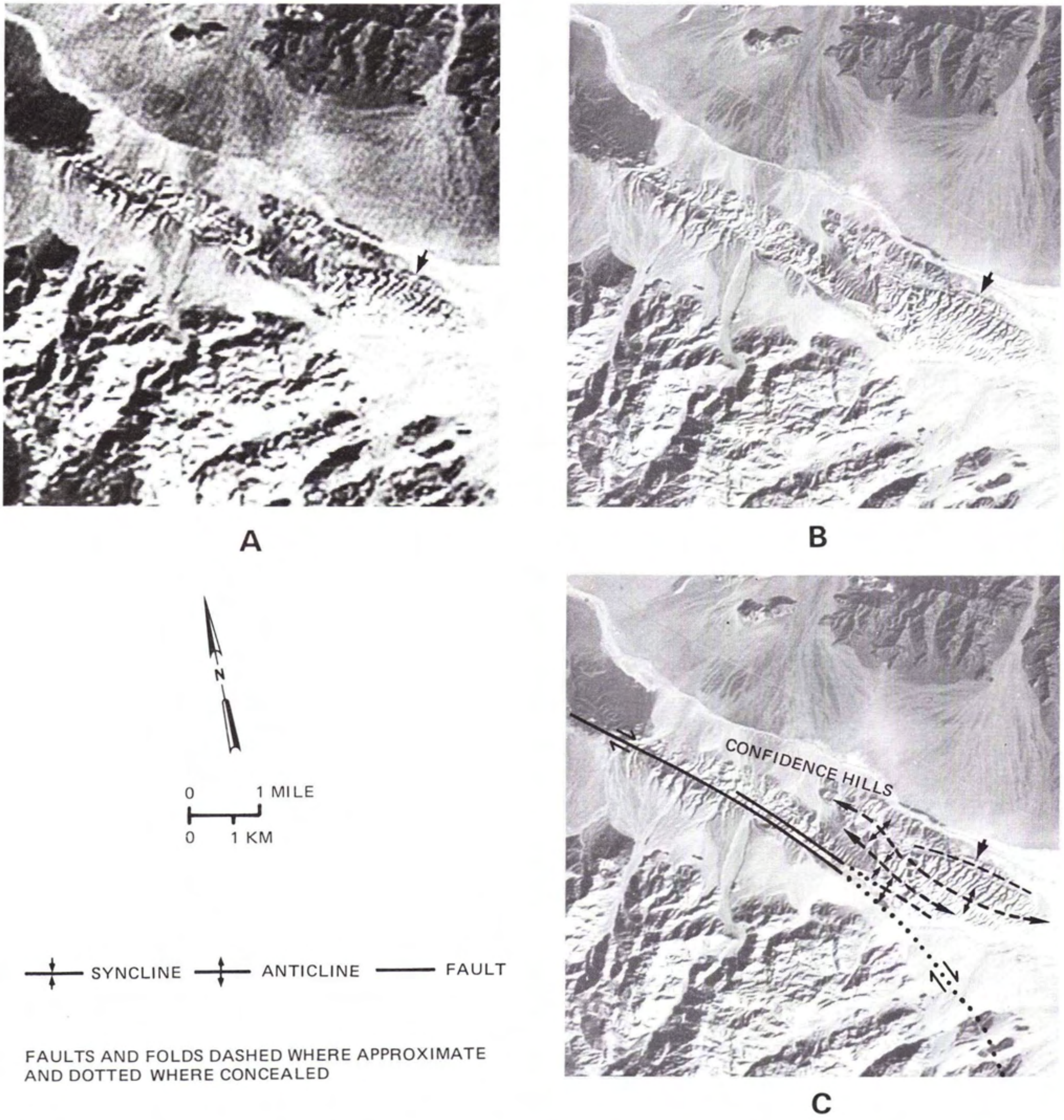

FIG. 3. Simultaneously acquired Landsat-4 MSS and TM imagery, presented at the same scale, showing the Confidence Hills in southern Death Valley. (A) Composite of MSS band-passes 1, 2, and 4, reproduced here in black and white. (B) Composite of TM band-passes 2, 3, and 4 reproduced here in black and white. (C) TM composite (same as B) annotated with field-mapped structural features (from Butler (1983)). Flatirons at the arrow are indistinct on the MSS image but easy to recognize in the TM image.

and Bennie Troxel, University of California, Davis, generously provided unpublished field maps. Colleagues at Exxon Production Research Company made contributions as follows: T.P. Harding, H.R. Hopkins, J.R. Kyle, C.W. Wielchowsky, and F.V. Corona developed interpretation criteria used to identify structural features in Landsat images, and N. Christie-Blick, D.W. Phelps, and T.P. Harding provided information on the geology of Death Valley.

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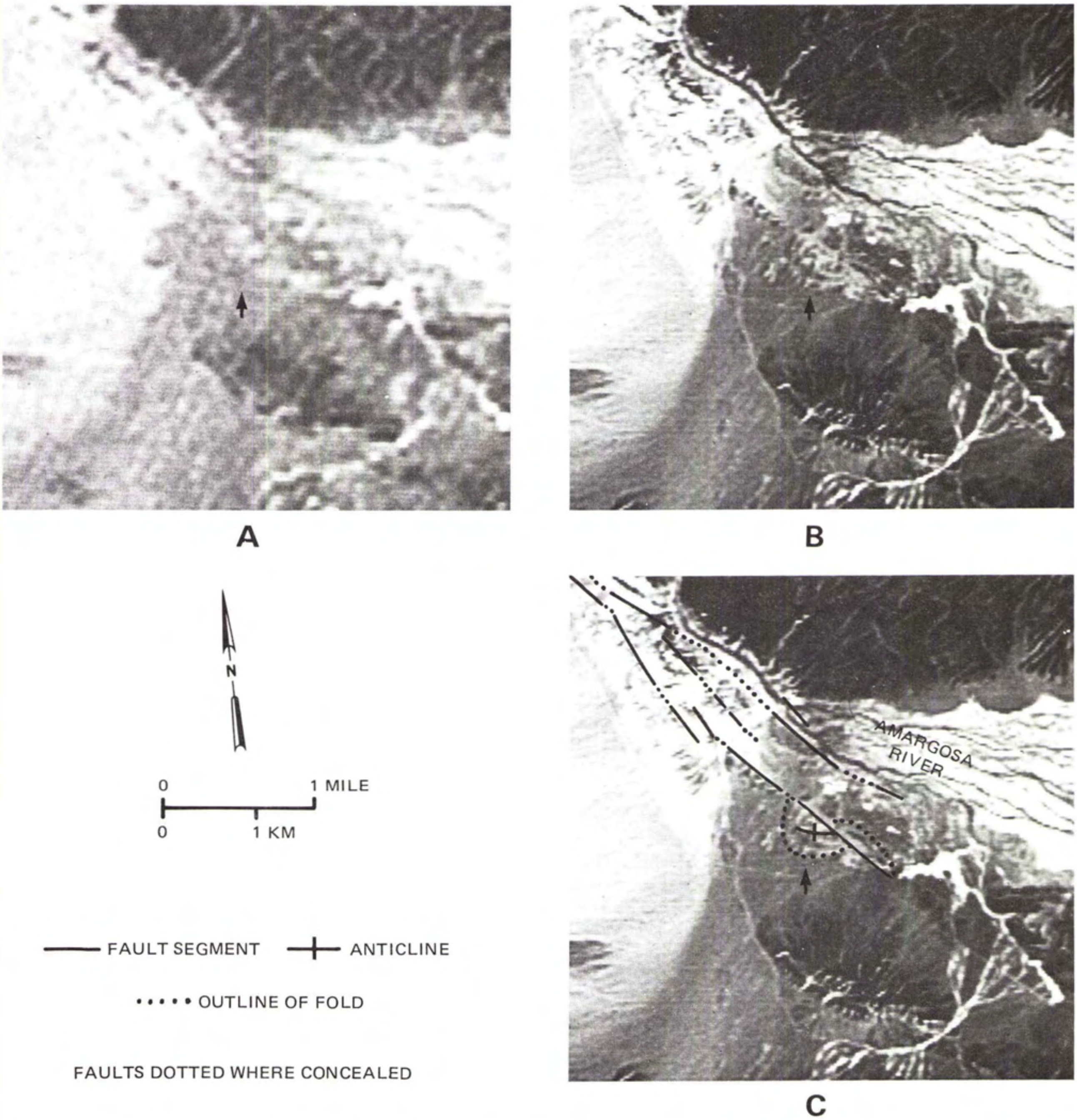

FIG. 4. Simultaneously acquired Landsat-4 MSS and TM imagery, presented at the same scale, showing a portion of the southern Death Valley fault zone near the Amargosa River. (A) Composite of MSS band-passes 1, 2, and 4, reproduced here in black and white. (B) Composite of TM band-passes 2, 3, and 4, reproduced here in black and white. (C) TM composite (same as B) annotated with field-mapped structural features (from Butler (1983)). An *en echelon* fold cut by a fault (at the arrow) is distinct in the TM image, but unrecognizable in the MSS image.

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(Received 1 January 1987; accepted 14 March 1987; revised 15 May 1987)