REMOTE SENSING TECHNOLOGY IN SUPPORT OF GEOPHYSICAL OPERATIONS*

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ABSTRACT

Remote sensing technology was utilized to generate large-scale images, basemaps, and topographic maps in support of seismic and gravity operations in Yemen. Prior to this application of remote sensing technology, only small-scale basemaps and topographic maps (1:500,000 scale) of the area were available. Landsat TM and SPOT images were used to construct a reliable basemap and to help plan an ex-tensive seismic and gravity program across this rugged terrain. Stereo, panchro-matic SPOT images and 11 GPS ground control points were used to create a digital elevation model (DEM) with a 10-m grid that covered about 50 x 100 km in area. Topographic maps were generated from this DEM with scales varying from 1:100,000 to 1:25,000 and contour intervals from 50 to 10 m. The topographic maps were most useful for regional planning and field operations. Large-scale maps (1:25,000) with 10 m contours required careful implementation because the algorithm that generated the DEM displayed steep, near-vertical cliffs as rounded features. This project demonstrates that timely and practical application of remote sensing technology can support more efficient and cost-effective field operations.

1.0 INTRODUCTION

Chevron International (Yemen) Ltd. concluded a Production Sharing Agreement for the Shabwah Gardan Block in Jannuary 1991 and initiated an exploration program. This area is characterized by varied terrain consisting of relatively low relief desert in the west and a large, flat high plateau in the east bounded by towering cliffs and deeply incised drainage (Figure 1). The work program included seismic and gravity data acquisition and regional and detailed geologic mapping, all supported by remote sensing technology. To effectively support the field operations and logistics planning, images needed to be made available early in 1991. Improved basemaps and topographic maps needed to be delivered by the end of 1991.

2.0 PLANNING/MAPPING IN THE OFFICE

An extensive seismic and gravity program was planned across this rugged terrain using Landsat TM imagery (bands 7, 4, 2 displayed as red, green, blue) enlarged to 1:100,000 (Figure 2). Initially a seismic grid was designed based on regional aeromagnetic and gravity data (Figure 2A). However, this original grid was significantly modified when integrated with the Landsat image (Figure 2B). Landsat interpretation also modified the spatial distribution of published geologic formations (Figure 3A). Mapping at scales greater than 1:100,000 was difficult because of the 30 m ground resolution of Landsat TM.

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3.0 MERGING LANDSAT TM AND SPOT FOR FIELD OPERATIONS

Near-vertical SPOT images were digitally merged with color Landsat and plotted in color at 1:50,000 for detailed field work and locating Global Positioning System (GPS) fixes in the field (Figure 4). This digital integration utilized the IHS transformation on the 3 Landsat bands (the black & white SPOT image was substituted for the TM's intensity image). The TM/SPOT colors were easily correlated to terrain conditions across the barren terrain (Figures 5-7). The correlation of image colors with accessibility enabled field crews to alter their routing to maximize data acquisition in the field.

Field crews and surveyors obtained GPS fixes and noted the location of these sites on the TM/SPOT color images. This enabled the Latitude and Longitude of these GPS sites to be keyed into the company's computer-aided drafting (CAD) mapping system and correlated with the field-annotated images. The images were rectified to the region's UTM map projection and local datum. Northing/ Easting and Latitude/Longitude grids were embedded into the images and large-scale plots were delivered to field crews by April 1991.

4.0 GENERATING A DIGITAL ELEVATION MODEL (DEM)

Vertical relief poses a formidable field problem within the Gardan Block as elevations range between 800 and 1800 m ASL. Steep cliffs and incised gorges characterize much of the license area (Figure 8). Only small-scale basemaps and topographic maps (1:500,000 scale) were available for the Block. In order to construct a usable topographic map, Chevron International (Yemen) Limited ordered stereo, high resolution (10 m) SPOT imagery, initiated a GPS acquisition progam across the Block, and contracted Hughes STX for generation of a DEM. The DEM was also needed to provide elevation data for gravity terrain corrections, minimizing expensive field surveying.

Two pairs of black and white SPOT images were acquired by February 1991, one set with a near-vertical viewing angle (Figure 9A) and the other set with an oblique viewing angle of 18°. The base-height ratio was 0.37 and vertical exaggeration was 2.5. The SPOT pairs were plotted at various scales for traditional photogeologic interpretation with stereoscopes.

GPS control points obtained with a single-station receiver by field crews could not be used for generation of a DEM. The inherent locational error in a single-station GPS fix and/or errors in the field crews locating themselves on the image prevented the algorithm that is utilized by Hughes STX from generating a satisfactory solution. Professional surveyors were contracted in July 1991. They utilized at least 2 GPS receivers in the differential mode and obtained 11 ground control points across the Gardan Block. With these 11 GPS points, a DEM was successfully generated by October 1991 with a 10 meter grid interval for each SPOT pair. The internal quality of this DEM was estimated at ± 25 m (x, y) and ± 12 to 15 m (z) (equivalent to r.m.s.). The DEM covered 50 x 100 Km. At each grid node, an elevation was provided to the nearest meter.

Because of the fine grid cell and an extensive null area around the model, the DEM exceeded 110 Mbyte in size and was loaded onto Chevron's Cray for processing. The DEM was converted from its integer 16-bit format (elevation in meters ranging from 800 to about 1800) to byte data (elevation range compressed to 256 levels). These byte data were artificially illuminated (Figure 9B) as described by Kowalik and Glen (1986) to check data quality and provide a topographic overview of the terrain. Compressed data sets (250 and 100 m grids) were generated for many applications. A DEM with a 100 m grid interval provided an elevation control point every 1 mm for a topographic map at 1:100,000 scale. Compressed DEM's were processed on a variety of workstations.

5.0 GENERATING TOPOGRAPHIC MAPS FROM THE DEM

The DEM could be artifically illuminated (Figure 9B), displayed as a gray-scale image, and given generic contours within our image processing systems (Figure 10). However, integration with company base maps and construction of useful topographic maps required transferring the DEM at various grid intervals and dimensions to the company's CAD mapping system. The size of the DEM had to be limited to about 1000 lines x 1200 samples in order to be processed on CAD workstations.

The DEM was transferred as an ASCII flat file of x,y,z values. The DEM was already in the local map projection. A contouring package within the CAD environment generated topographic maps (Figure 11) at scales ranging from 1:100,000 to 1:25,000 and contour intervals from 50 to 10 m. By November 1991 topographic maps were being delivered to the field.

6.0 INTEGRATING OTHER DATASETS WITH THE TOPOGRAPIC MAP

Within the CAD environment, geologic maps, seismic lines, well locations, and enhanced Landsat and SPOT images were co-registered to the local datum. The topographic maps that were generated within CAD were easily co-registered to these other map and image files, allowing topographic contours to be embedded into all of these datasets (Figures 12 and 13). Plots displaying integrated maps and images were being delivered by December 1991.

7.0 EVALUATING THE DEM AND DERIVED TOPOGRAPHIC MAPS

The internal quality of the DEM was initially estimated at ± 25 m (x, y) and ± 12 to 15 m (z). As field operations progressed, we initiated a program to compare the accuracy of the DEM with elevations that were surveyed along each seismic line (Figure 14). Overall, most of the model is within ± 15 m of the surveyed elevations, which is remarkable considering that only 11 ground points with known x,y,z values were used to help generate a model that contains about 50,000,000 nodes or pixels, each with its own set of x,y,z values.

The DEM dips slightly to the east compared with surveyed elevations. This slight tilt did not degrade the topographic maps. However, the DEM algorithm modelled steep cliffs as topographically rounded features and introduced anomalous cones and depressions across some flat areas (Figure 15). Stereoscopic viewing of the overlapping SPOT images and field-checking confirmed that these features were DEM errors.

The algorithm's correlation kernal (used to correlate pixels between the overlapping SPOT images) had an inherent limitation with steep and high cliffs, especially those trending north-south. The algorithm would alter the top edge of these cliffs and their talus-covered bases into topographically rounded features. The top and bottom edge of cliffs were horizontally offset in an east-west direction on overlapping SPOT images, because each image was acquired with a different, off-nadir viewing angle. This horizontal offset (parallax) allows for stereoscopic viewing and determination of elevation by the DEM program. However, this horizontal offset also resulted in the kernal, as it moved across the overlapping images correlating pixels, encountering numerous correlation gaps as it approached and departed the edge of precipitous cliffs.

The distance affected by the correlation gap was related to the change in elevation between the top of cliffs (detected on one image) and the lower terrain (detected on the other image). Within these correlation gaps, the algorithm generated inaccurate elevations as it averaged the height difference between the high cliff and lower terrain. Across the deeply-incised high plateau of the Gardan Block, the DEM produced elevation errors (excessive topographic rounding) about 20 pixels before the true edge of the top and bottom of the most precipitous, N-S trending cliffs (Figure 15).

The anomalous topographic cones and depressions could have been edited out of the DEM by the contractor, but our delivery deadline precluded such action. For some in-house gravity work that utilized a DEM with a 100 m grid interval, these anomalies were identified by a workstation operator and corrected.

These problems with cliffs and flat areas were most apparent on large-scale (1:25,000) topographic maps created from the 10 m grid and contoured with a 10 m interval. These problems are least apparent on smaller-scale maps (1:50,000 and 1:100,000) generated from compressed grids and contoured at larger intervals.

8.0 SUMMARY

More efficient field operations, greatly improved basemaps, and unique topographic maps were realized by timely and practical application of remote sensing technology. The Landsat and SPOT images were critical for planning and field operations. The DEM constructed from stereo SPOT and GPS control provided a series of topographic maps that were integrated with company CAD maps and enhanced satellite images. As required, images, basemaps, and topographic maps were delivered to the field during the first year of the exploration work program.

9.0 ACKNOWLEDGEMENTS

We acknowledge Brian Kay and Jan Smith of Chevron International (Yemen) Limited, Chevron Overseas Petroleum Inc. (COPI), AGIP, and the National Petroleum Co. of Yemen for permission to publish this paper. Chevron International (Yemen) Limited provided continuous support for this remote sensing project. Chris Welch of COPI correlated TM/SPOT colors and textures with terrain conditions and together with Nick Gant supplied the field photographs. Nick Gant and Roubik Avanessians of COPI compared surveyed elevations with the DEM. Bill Kowalik and Scott Hills of Chevron Oil Field Research Company provided technical assistance for manipulating and enhancing the DEM. COPI's Remote Sensing and CAD Drafting groups, in particular Mark Choiniere, Mike Quinn, Hattie Davis, and Pat Caldwell, created the images and maps. Finally, Richard Irish and Jeff Olsenholler of Hughes STX provided excellent technical support and ensured timely delivery of the DEM.

10.0 REFERENCE

W.S. Kowalik and W.E. Glenn, 1987, Image processing of aeromagnetic data and integration with Landsat images for improved structural interpretation: Geophysics, vol. 52, no. 7, p. 875-884.

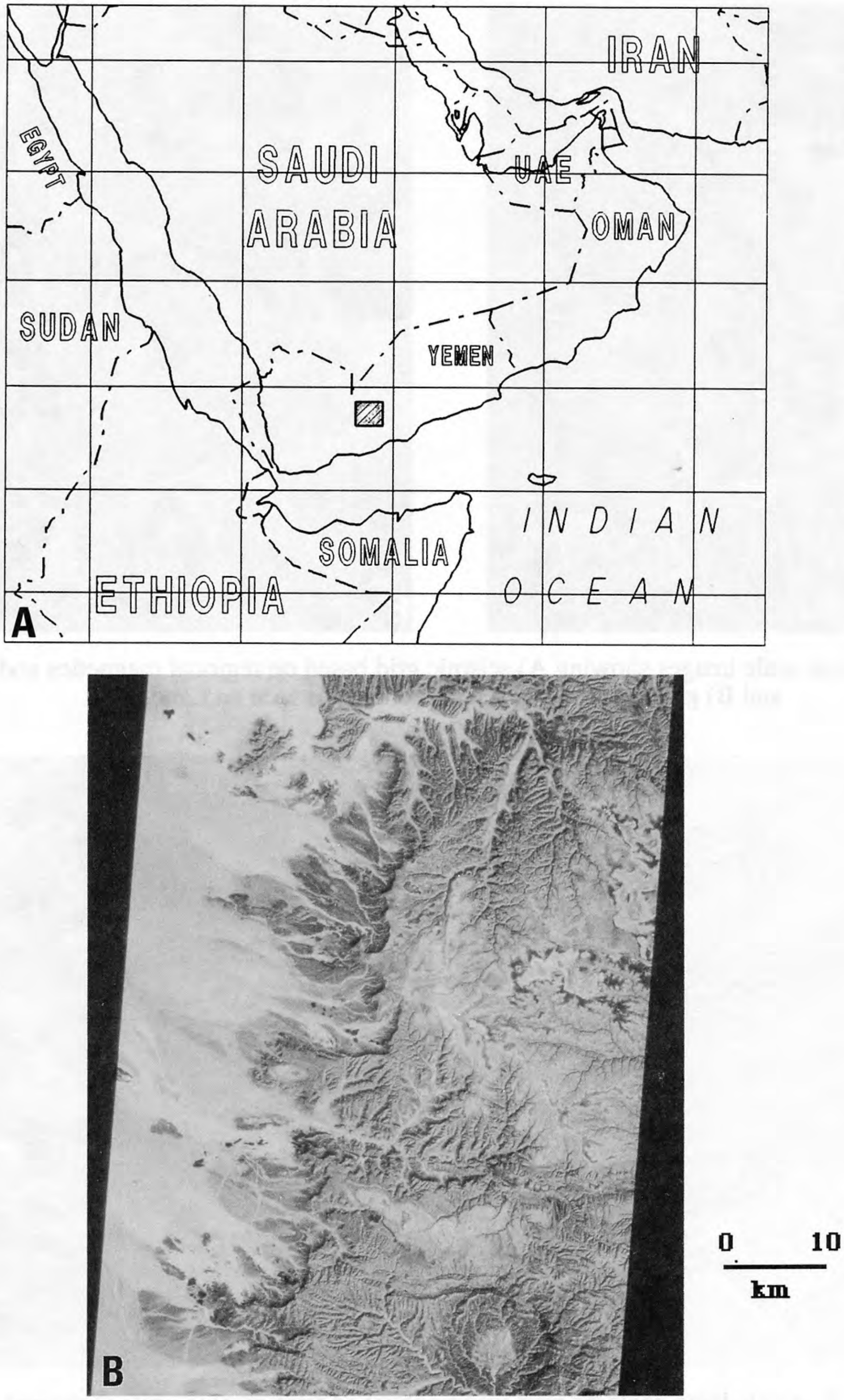

Figure 1. A) Location map of Yemen and B) regional Landsat image (location of image shown on map as shaded area).

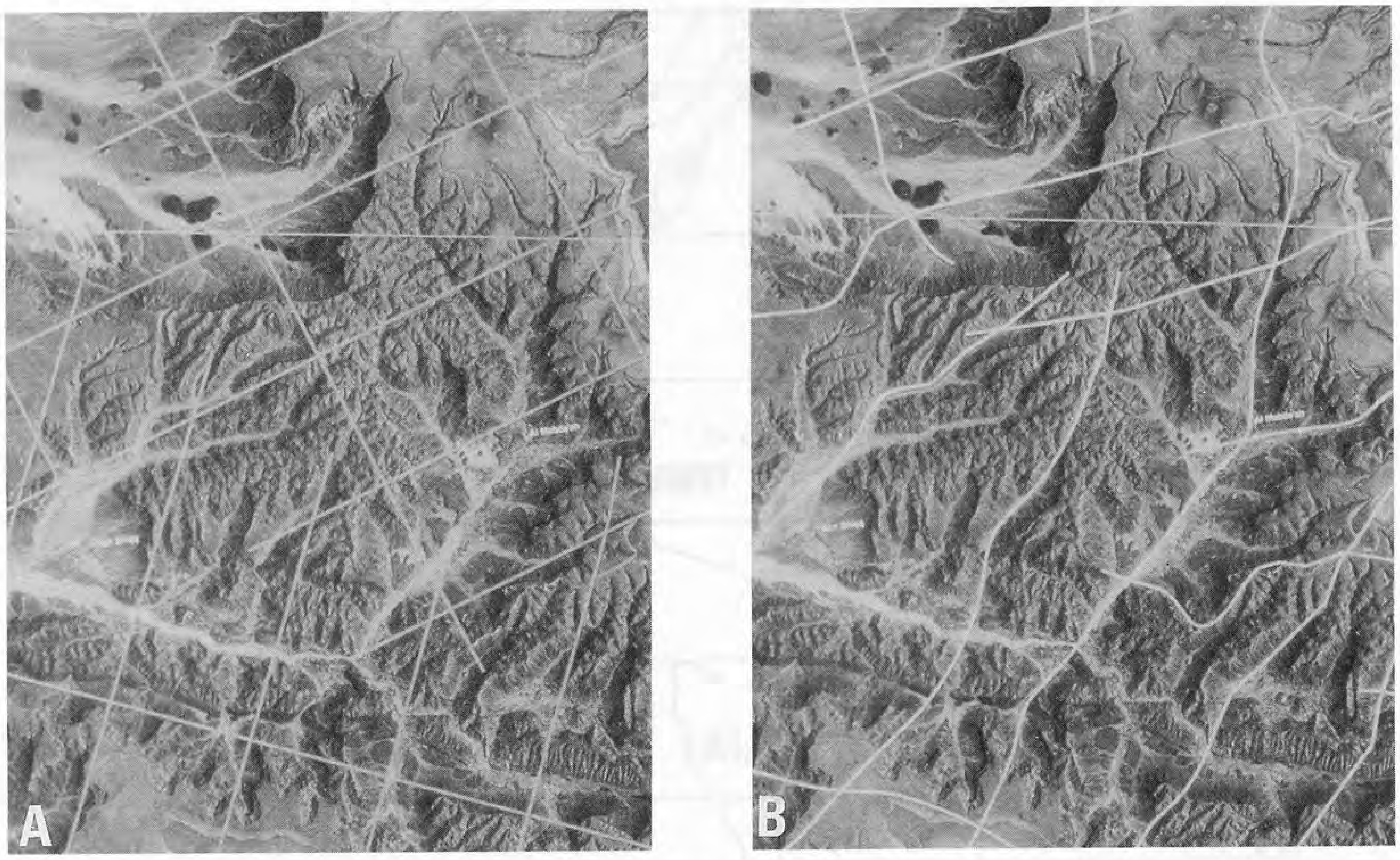

Figure 2. Same-scale images showing A) seismic grid based on regional magnetics and gravity, and B) grid modified by terrain conditions seen on Landsat.

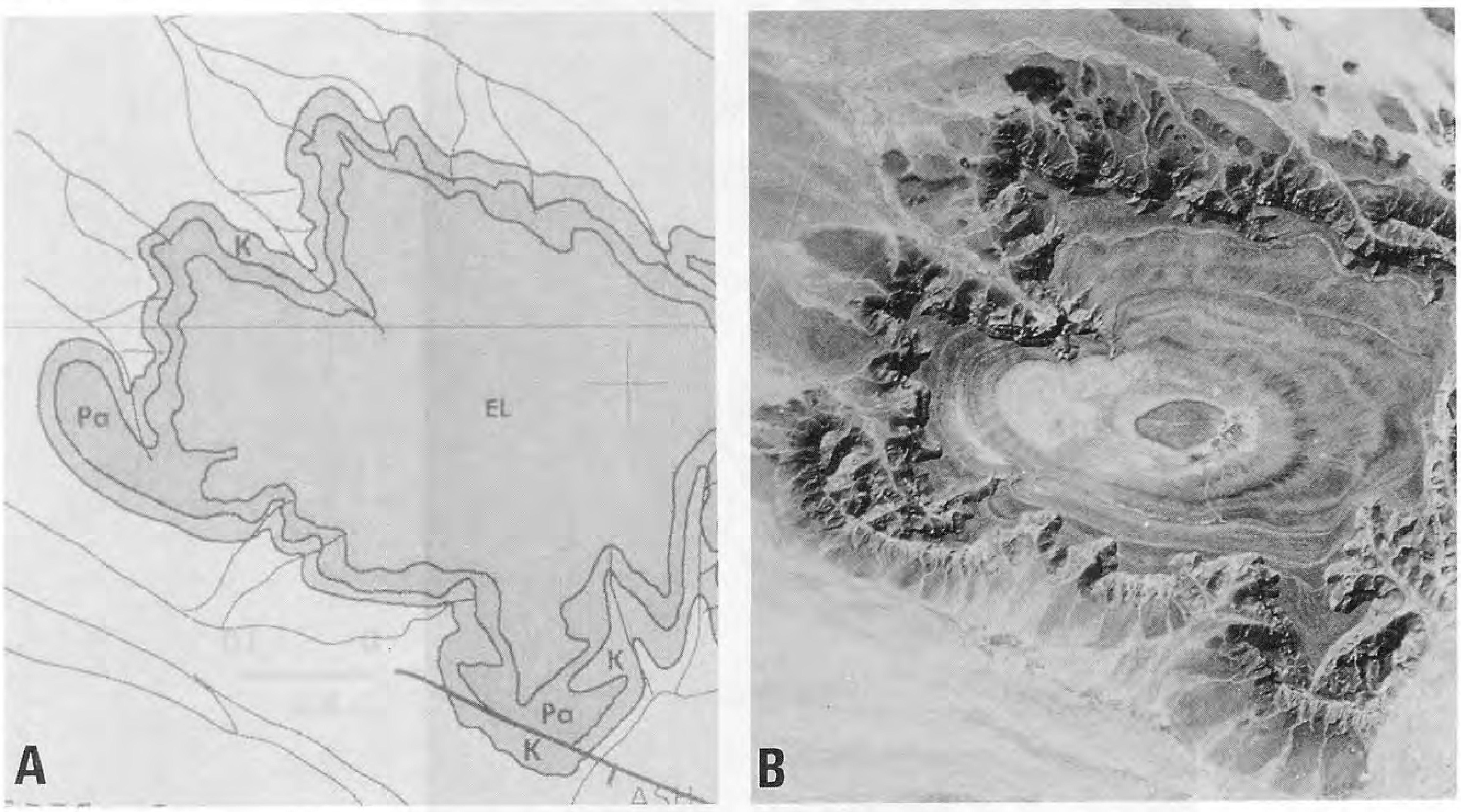

Figure 3. A) Updated geologic map using published stratigraphic units compared to B) additional stratigraphic information available on black & white rendition of digitally merged Landsat TM (742 as RGB) and panchromatic SPOT image. SPOT © 1991 CNES

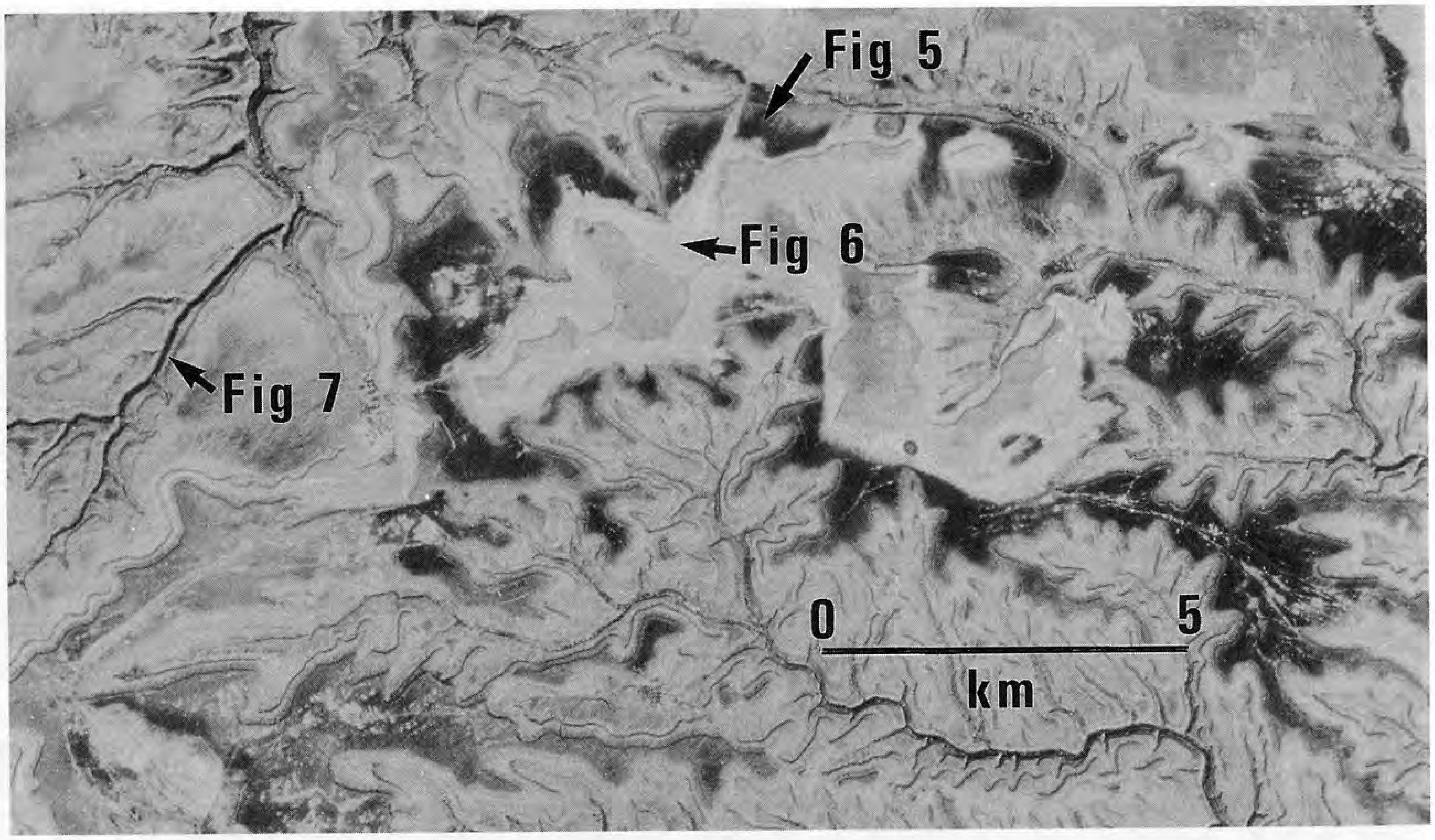

Figure 4. Landsat TM/SPOT image showing typical plateau terrain with arrows indicating field localities shown in Figures. 5-7. SPOT © 1991 CNES

Figure 5. Difficult terrain with eroded chert nodules forming lag deposit on top of limestone unit (see sunglasses in foreground for scale; arrow on Figure 4 points to this type of terrain).

Figure 6. Smooth, easily traversed terrain on plateau (arrow on Figure 4 points to this terrain type on Landsat/SPOT image).

Figure 7. Incised, steep-sided gully that poses a problem for field operations and seismic processing (see arrow on Landsat/SPOT image of Figure 4).

Figure 8. Scenic view looking south at steep cliff termed the "hook" in subsequent figures (see Figure 1 for location).

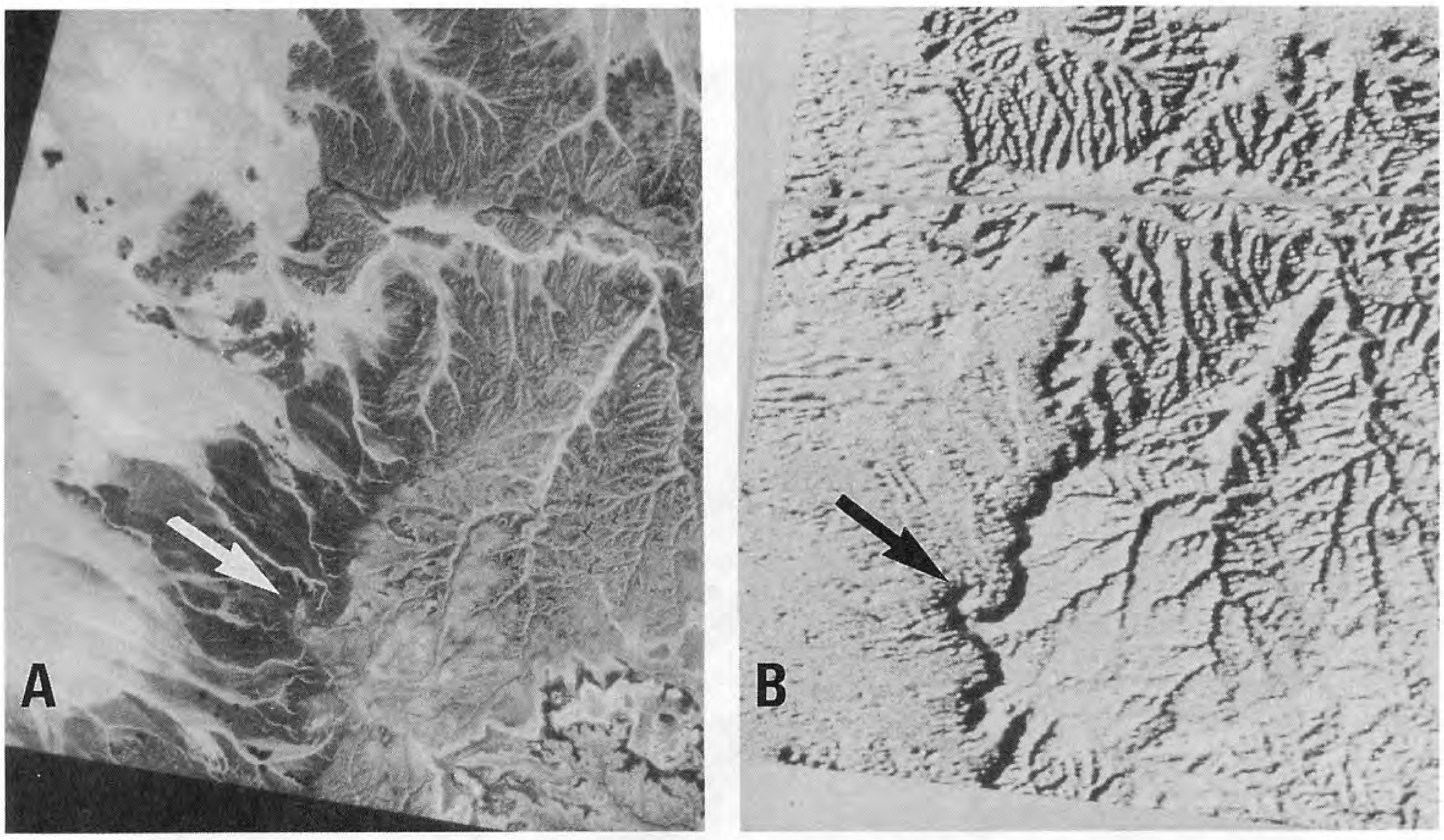

Figure 9. A) Panchromatic SPOT image showing steep cliffs, desert on the right and plateau on the left with same-scale B) DEM artifically illuminated from the east (arrow points to the "hook").
SPOT © 1991 CNES

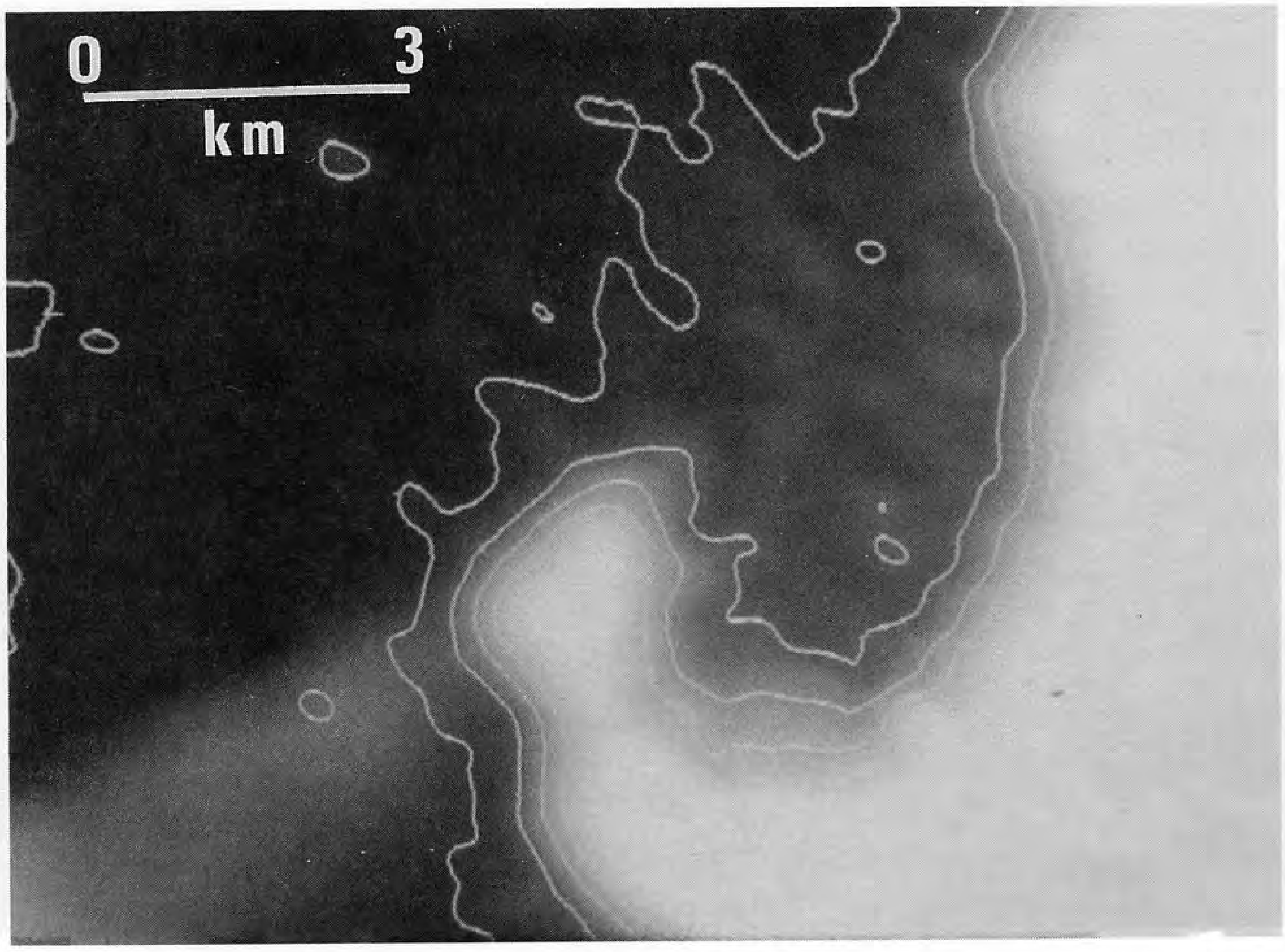

Figure 10. Close-up of DEM over the feature termed the "hook" (same-scale images and maps shown in Figs. 11-13). Contour interval of topographic contours is 100 m.

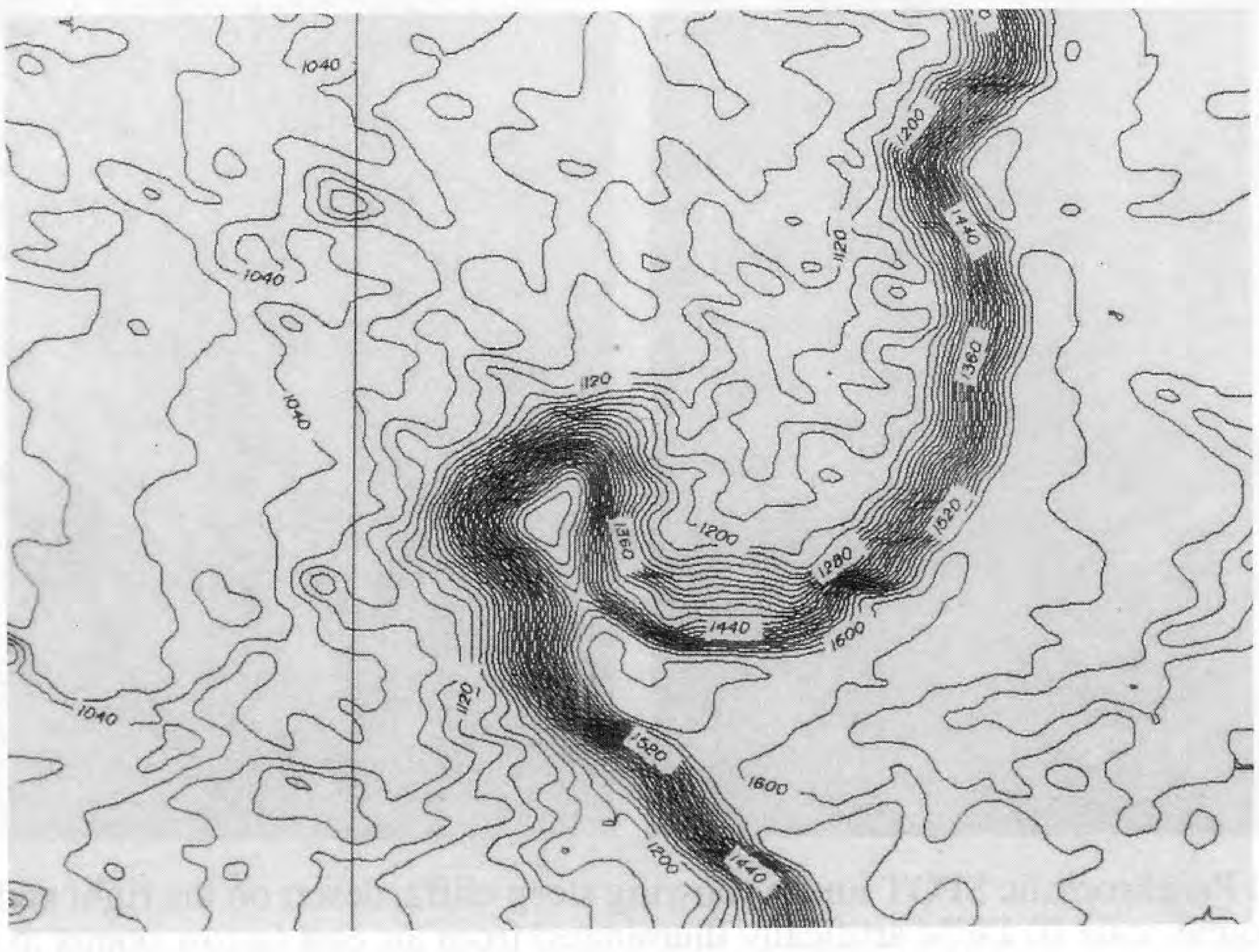

Figure 11. Close-up of topographic map of "hook" with 20 m contour interval

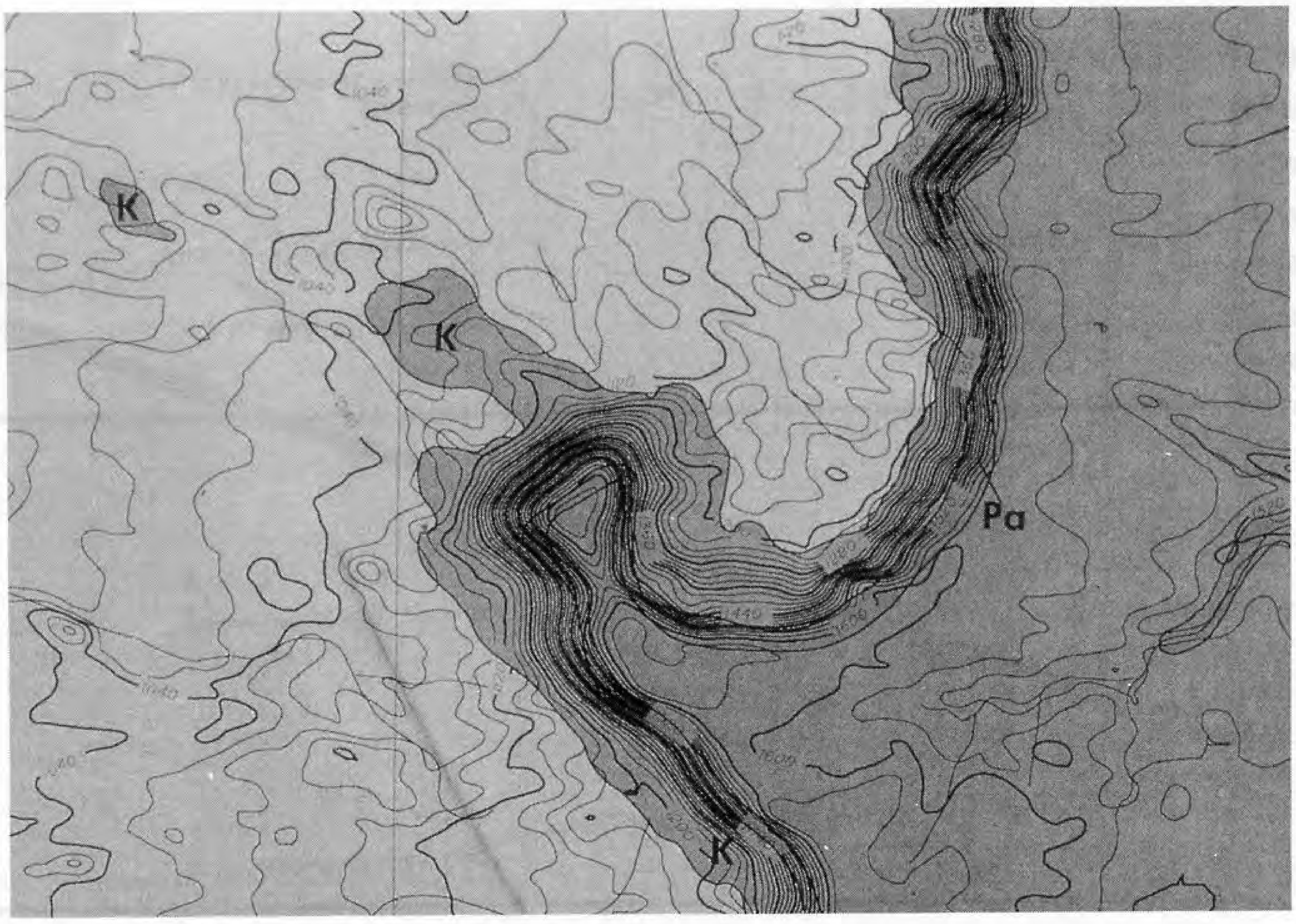

Figure 12. Close-up of the "hook's" topographic map integrated with geologic map.

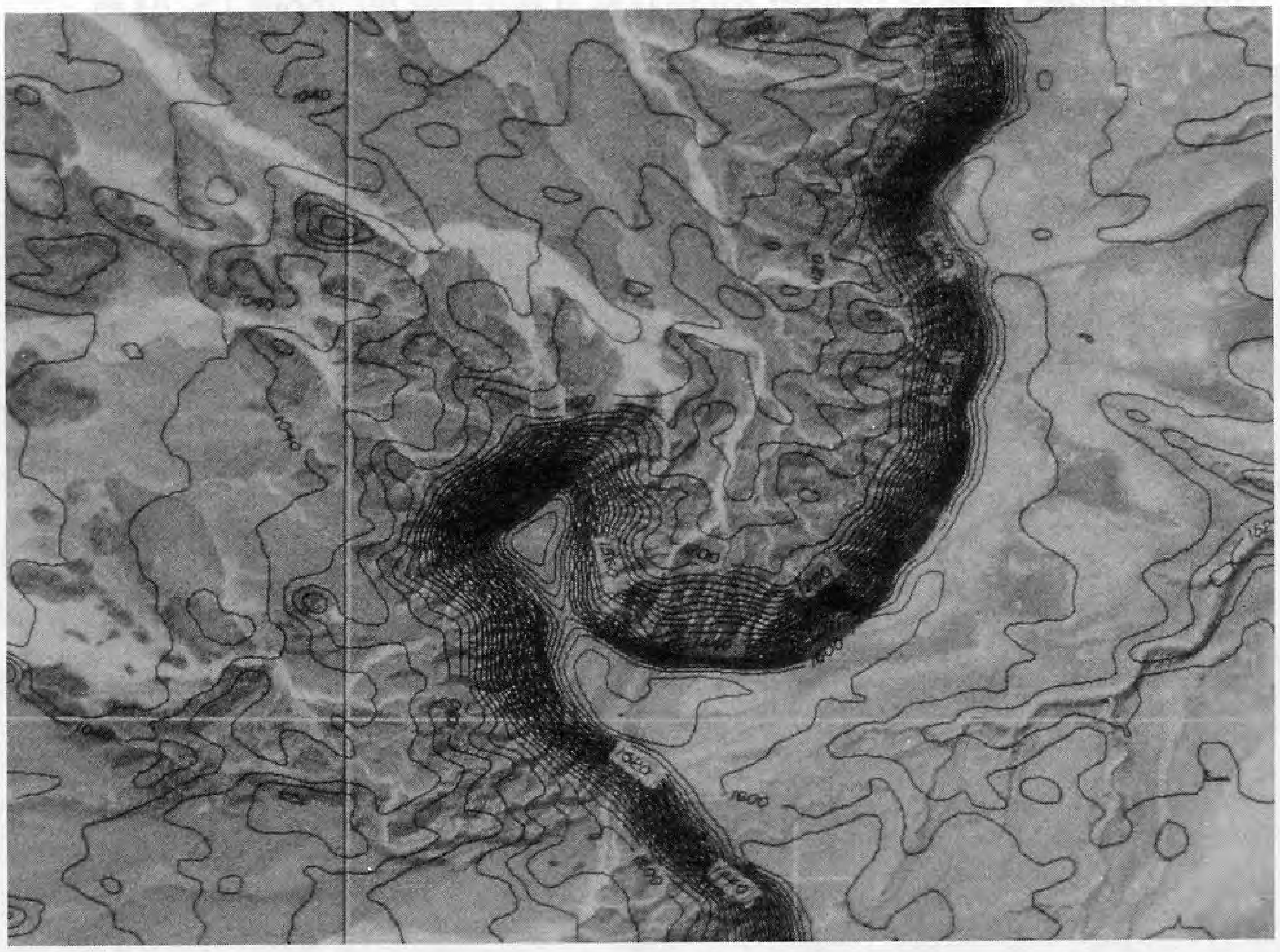

Figure 13. Close-up of the "hook's" topographic map integrated with Landsat TM/SPOT image. SPOT © 1991 CNES

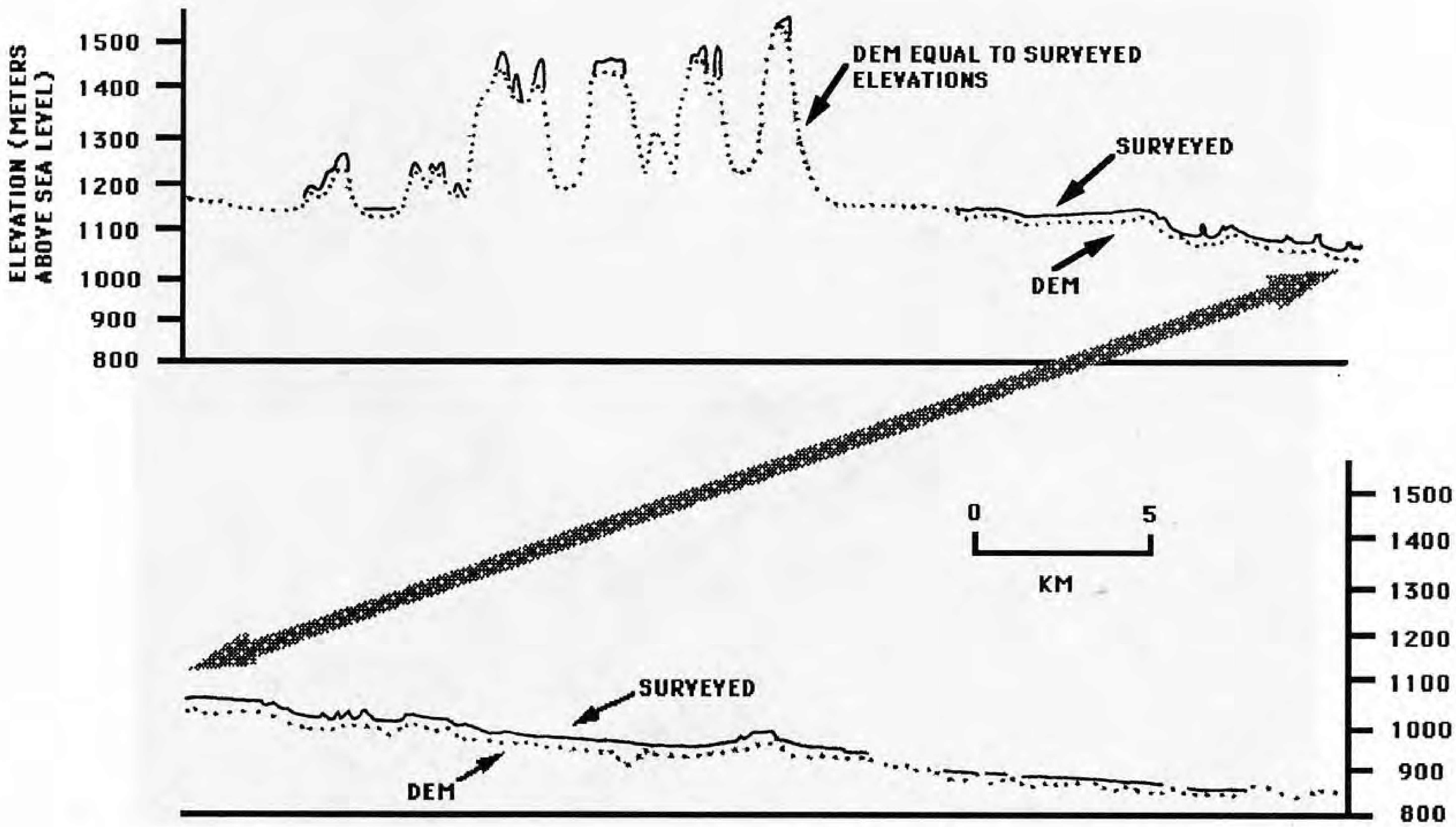

Figure 14. Profile showing difference in meters between DEM and surveyed elevations taken in the field along one seismic line. Agreement is good overall. Peaks are generally lower in DEM and rounded. DEM's slight tilt makes it too low by about 15-20 m.

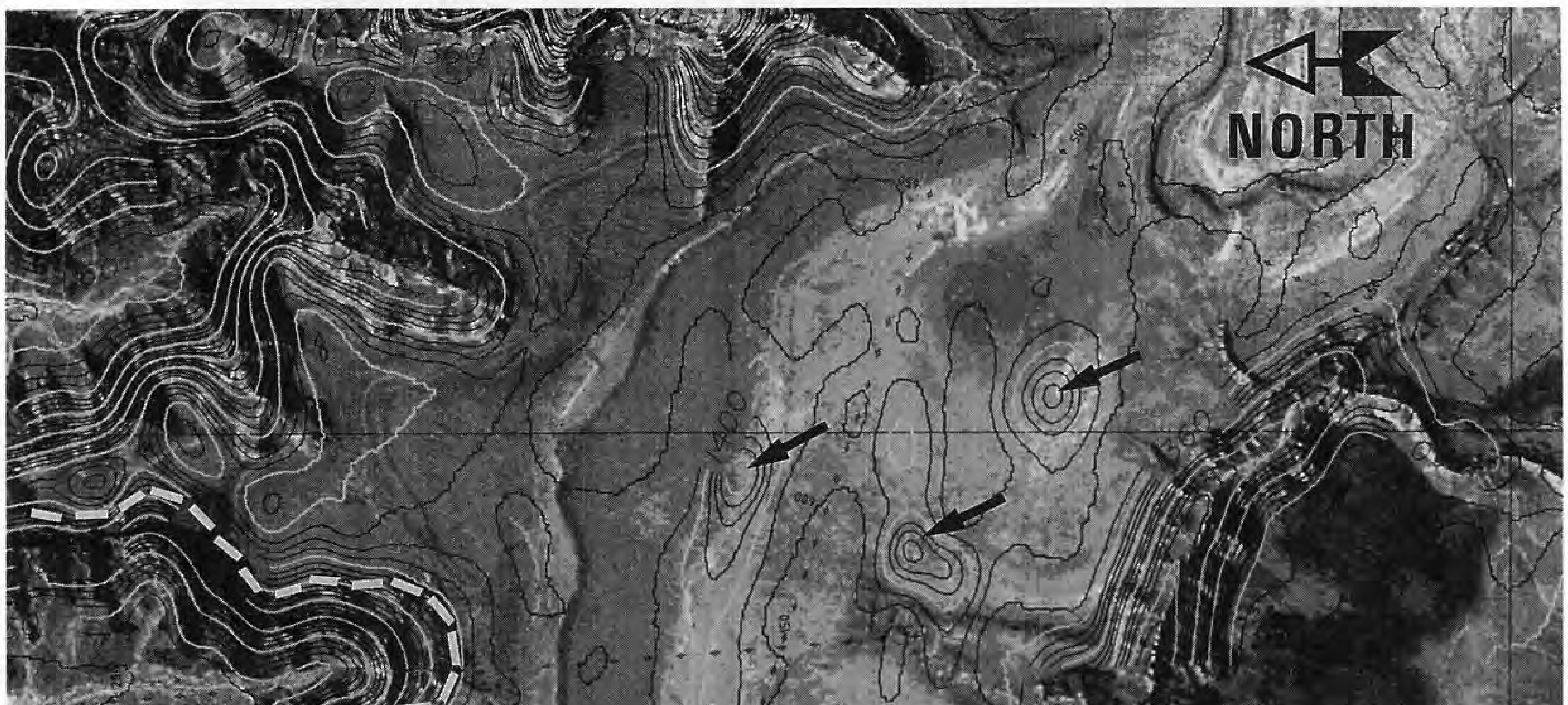

Figure 15. Large-scale plot (generated from 10 m grid and contoured at 10 m interval) showing problems with rounded cliffs (dashed line outlines true edge of cliff as seen on SPOT stereo pair) and with random cones and depressions on flat areas. Problems are less evident on smaller-scale maps and DEM's made from larger grid intervals (100 and 250 m). SPOT © 1991 CNES

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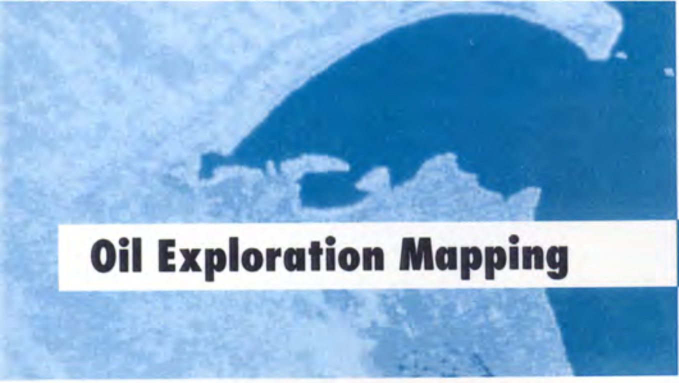

Oil Exploration Mapping

Environment and Resources Management

In January 1991, Chevron International (Yemen) Limited concluded an agreement with the newly established Republic of Yemen for oil exploration and production sharing in an area of Yemen known as the Shabwah Garden Block, an area characterized by rugged and varied terrain, including low relief desert, high plateaus, towering cliffs and deeply incised drainage.

To support field operations and logistics planning, the company needed detailed geologic and topographic maps, but only small-scale base maps of the area were available. Chevron therefore initiated a remote sensing project to develop a digital elevation model, and to generate large scale images, improved base maps and topographic maps. The job fell to Chevron Overseas Petroleum Inc. (COPI), San Ramon, California and COPI remote sensing supervisor James M. Ellis, with assistance from Chevron Oil Field Research's remote sensing laboratory at La Habra, California.

The remote sensing team used imagery from the NASA-developed Landsat Thematic Mapper (TM) and the French SPOT satellite, combining images from both into composite views to use the best capabilities of each system. **Below** is a TM/SPOT composite image of the Shabwah area typical of those used to extract a great deal of information for support of field operations; the white, gray and light blue shades in the west (left in image) are areas of flat, sandy desert, dry river courses and cobble/gravel surfaces, readily accessible to vehicles; red and pink signify limestone and shale areas; brown represents sandstone and green massive sandstone. The green area at bottom center is an area of steep to vertical canyons and cliffs that bar vehicular operations.

The project was successfully concluded within the specified time of 11 months with delivery to the field of images, greatly improved base maps and unique topographic maps. COPI's James Ellis reported: "This project demonstrates that timely and practical application of remote sensing can support more efficient and cost-effective field operations."