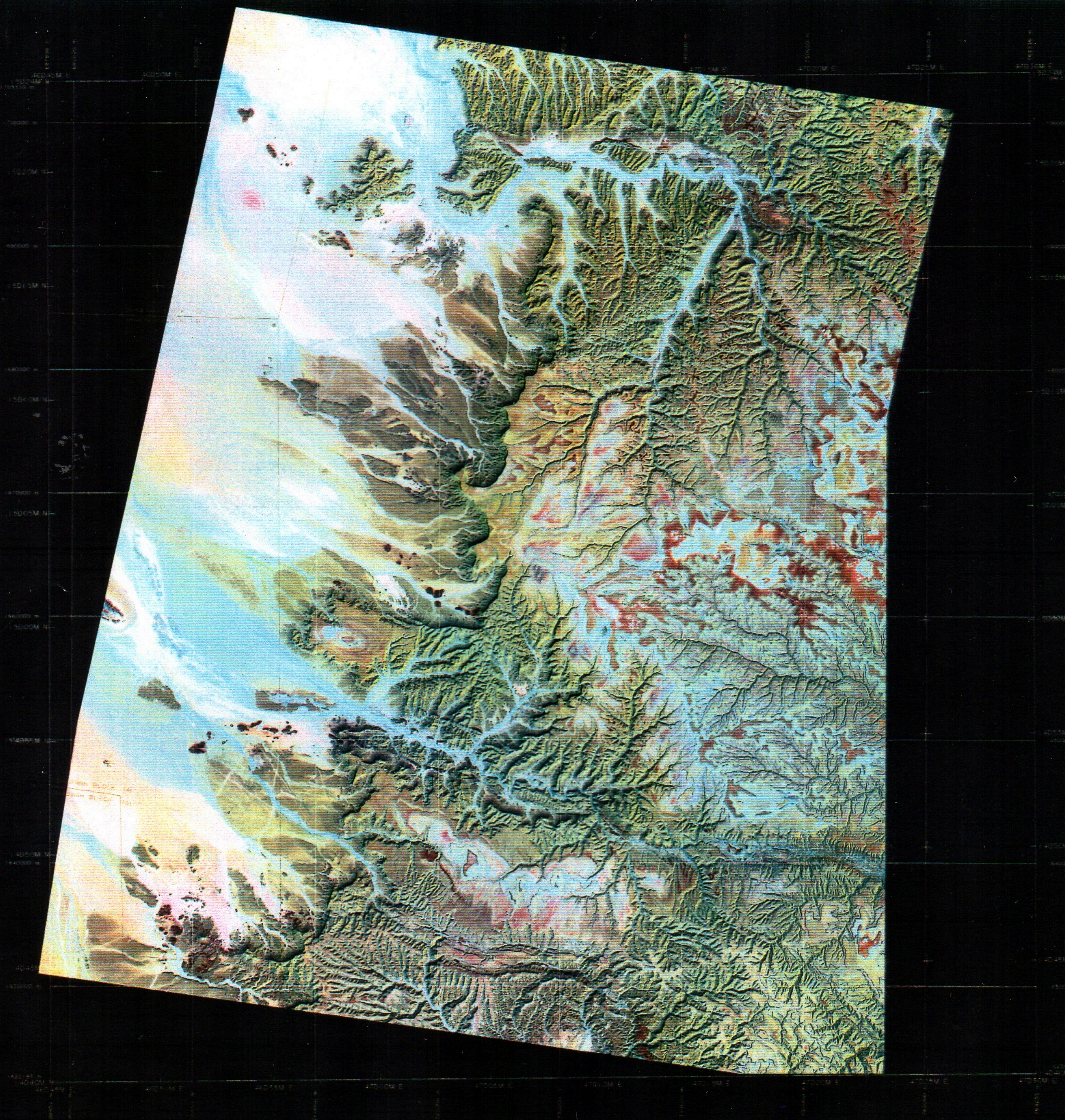


Chevron Overseas Petroleum Incorporated
San Ramon, California, USA
Gardan Block 3, Yemen
TM/SPOT merge with CAD overlay and TM splice

0 10 km

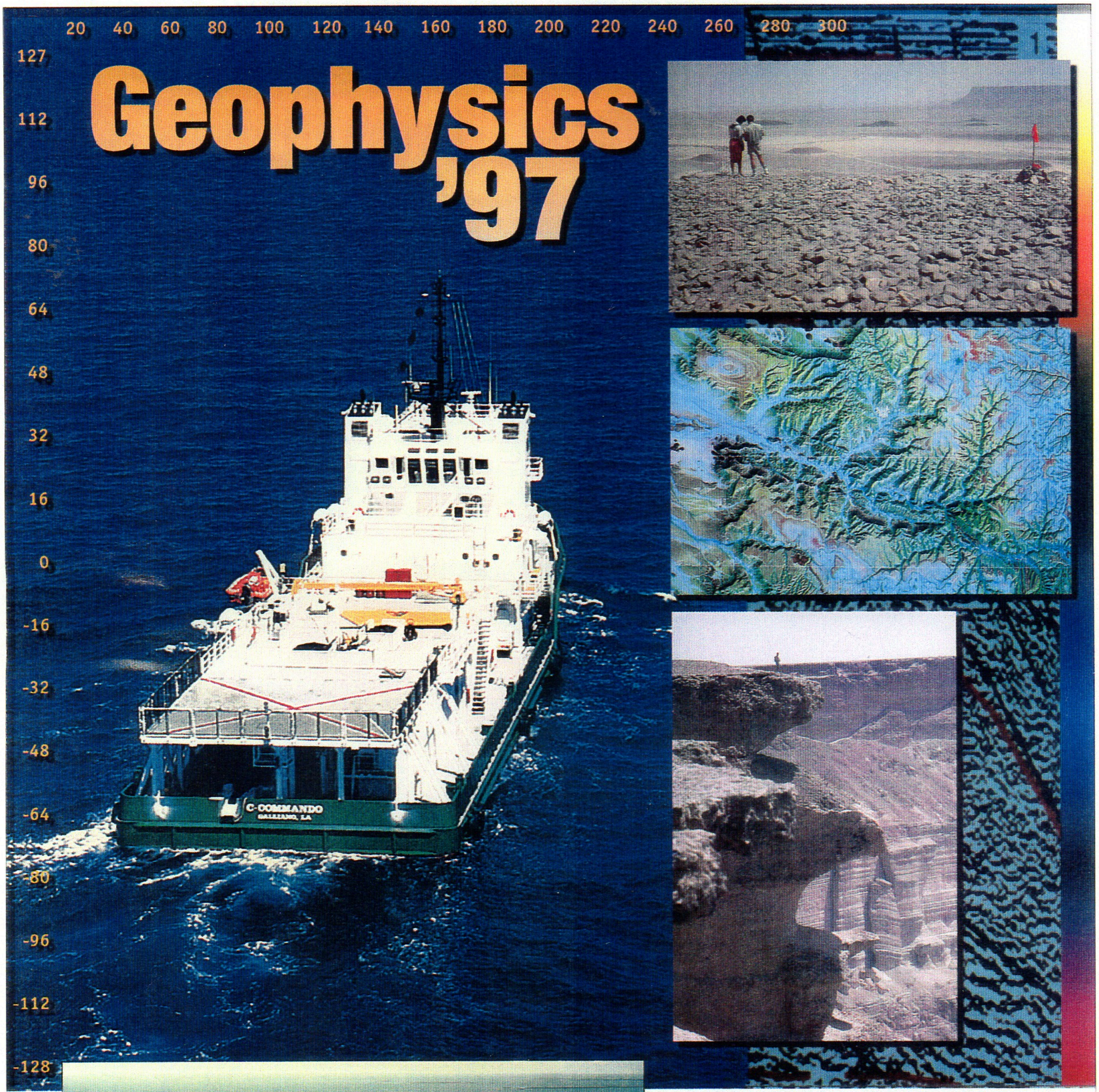
Red: Band 7	Green: Band 4	Blue: Band 2
Date Acquired: 27 Mar 88	Date Processed: 10 Jul 91	Scene ID: 42081-06393
Path: 164 Row: 049-050 Quads:	Aperture: 20.0x1 Microns	Fri Jul 12 09:10:09 1991

Process Applied: Spot acquired 28 Nov l990 K/J 152/319-320. TM INTE of IHS replaced with SPOT. 0315-00

AAPG AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, AN INTERNATIONAL ORGANIZATION

EXPLORER

NOVEMBER 1997



Going, going ...

The battle is on to save Louisiana's coastal environment.

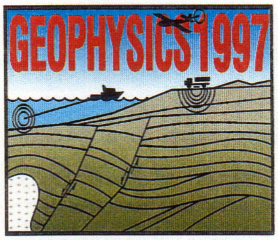
See page 34.

AAPG EXPLORER

'Pretty Pictures' Yield Value

Remote Sensing Enters New Era

By KATHY SHIRLEY
EXPLORER Correspondent



Remote sensing, once considered a gee whiz, novelty technique that produced interesting photographs of earth but little else, has entered a new era of application for petroleum, environmental and mining operations.

The technology has come of age, and for many oil companies it is a critical element in planning and implementing exploration and production programs throughout the world.

Since its civilian inception in the 1970s government agencies, private research organizations and oil companies have steadily advanced remote sensing and its applications to a broad range of problems throughout the petroleum and mining sectors – and experts say the next few years should bring a gigantic leap in the technique's effectiveness and its wide-spread use throughout the oil business.

"Remote sensing applications cover the gamut of petroleum operations and can save oil companies literally hundreds of thousands of dollars," said Rebecca Dodge, director of research and education for the non-profit Geosat Committee.

The technique, she continued, can be used to aid:

- Field operations and seismic acquisition planning.
- Geologic mapping, particularly in remote regions worldwide.
- Detecting and monitoring oil seeps and spills offshore.
- Environmental assessments.

"Those," she said, "just to name a few."

Patterns of Success

James M. Ellis, general manager of The Map Factory Inc., and former head of remote sensing operations for Chevron, agrees.

"Remote sensing allows the petroleum industry to make better and quicker interpretations of geological and environmental conditions in areas of present and future operations," he said.

"Often remote sensing, including aerial photography, is required because existing maps are out of date, too small of scale or provide only limited information. Implementing remote sensing can lead to lower project costs and reduced risk."

Dodge points out that "a whole new business sector has sprung up around remote sensing technology.

"New companies have been formed over the past 20 years to provide mapping and interpretation of the satellite data, to provide training for satellite imagery applications, and to actually launch the satellites and acquire the raw data," she said.

While remote sensing is a high-tech, computer-driven technique that can seem intimidating, Dave Koger, owner of Koger Remote Sensing in Fort Worth and chairman of the Geosat Committee, said potential users need to remember that this technology has its roots in aerial photography, which has played a role in finding oil and gas for decades.

"We are still looking for surface expressions of patterns, shapes and textures on the earth's surface that can provide clues to the subsurface," Koger said. "Although remote sensing uses

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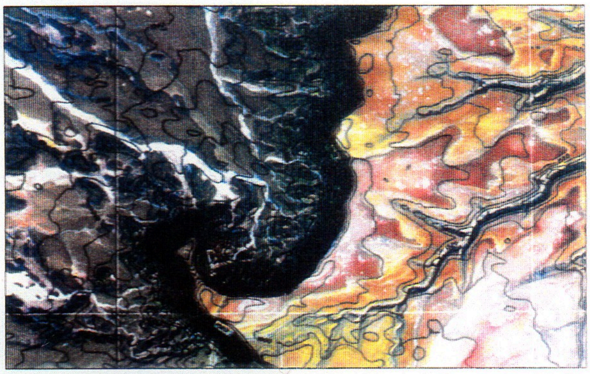

Photos courtesy of Jim Ellis

There was a time when remote sensing provided beautiful and interesting images. The images are still beautiful, but the technology's influence is growing.

continued from previous page

images from sophisticated space satellites, it is still photogeology."

Subsurface events critical for oil and gas exploration often do have expression at the surface, he added, and remote sensing techniques can highlight those surface expressions.

For example, faults, fractures, fracture orientation and joints can show up on the surface as linear escarpments, linear and right angle bends in drainage courses, moisture accumulation in springs, ponds or lakes in linear patterns, and aligned notches or ridge crests just to name a few.

"Remote sensing or photogeology can be the most effective first wave in exploration," he said, "to help pinpoint those areas with the greatest promise for more expensive traditional subsurface techniques like seismic, geochemistry, aeromagnetics, gravity and detailed well log analysis."

Commercial Realities

While new satellites are creating a great deal of excitement and anticipation, oil companies as well as groups like the Geosat Committee are already using remote sensing for a multitude of applications in the oil and environmental industries.

Since 1991 a major ongoing research project has been the Gulf Offshore Satellite Application Project, or GOSAP. The project was undertaken by Geosat members of the petroleum, marine and environmental industries representing several companies, government agencies and universities under the auspices of the Geosat Committee with the support of the European Space Agency.

GOSAP's goals are to determine how best to use remote sensing technology to address offshore problems and operations faced by exploration and marine engineering organizations.

"The GOSAP team is evaluating the potential for satellite-based offshore exploration, ocean engineering and environmental applications using combined satellite and airborne measurements constrained by real-time 'sea-truth,'" said Edward K. Biegert, physicist with Shell E&P Technology and GOSAP director, in a recent paper on the project's progress.

"Our experiments and comparison of observations of natural slicks and related phenomena from satellite imagery to sea-surface, water-column, and sea-floor measurements collected from fixed and mobile platforms in the Gulf of Mexico confirm that the satellite imagery is a valuable slick detection tool.

"GOSAP has taken this technology from a research status and demonstrated that it has definitely moved to a commercial footing," he said.

For the offshore petroleum industry GOSAP has illustrated the value of remote sensing technology as an exploration tool. The remote identification of hydrocarbon seeps is extremely valuable for geologists responsible for large or frontier offshore regions, Biegert said.

A notable achievement for GOSAP was the first "top down" seep detection. Armed with quick release images from the ERS - 1 (European Radar Satellite), scientists analyzed the SAR (Synthetic Aperture Radar) images, located the slick sources and directed a waiting surface vessel to the observed slick.

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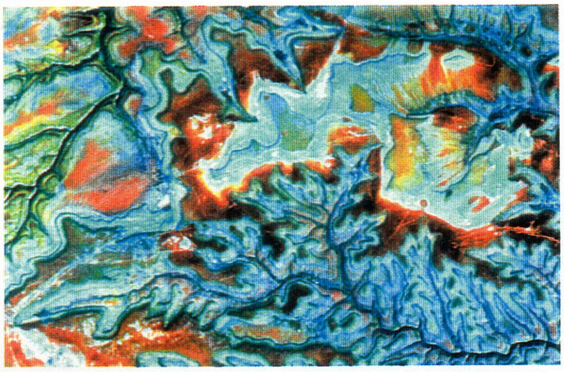

A good example from Yemen: The colors on the top image correlate with the actual ground conditions, helping explorationists to better study a hostile land.

Remote Sensing

from page 25

Once the vessel arrived, the crew collected surface samples and launched a special deep diving submarine to visit the most active seep sites and pinpoint seepage locations on the seafloor, he said.

Geosat/GOSAP members obviously see the value of remote sensing research and commercial applications to a variety of industries. Members, over the life of the project, have invested well over $13 million in direct project costs – and resulting proprietary applications.

"GOSAP participants," Biegert said, "are using the technologies developed and demonstrated in our project, are purchasing the satellite data for their own use and are purchasing value-added services and products developed by Geosat/GOSAP members."

Global Applications

Some oil companies are applying remote sensing technology extensively to operations all over the world.

Chevron Overseas Petroleum has used the technique to address a whole host of problems in regions such as the Tengiz Field in Kazakstan, Papua New Guinea, Colombia, Congo and Yemen.

In Yemen, Chevron used remote sensing technology to generate large-scale images, base maps and topographic maps in support of seismic and gravity operations, Ellis said. Prior to Chevron's effort, only small-scale base maps and topographic maps on the order of 1:500,000 were available over Chevron's exploration block.

"With Landsat TM and SPOT images we were able to construct a reliable base map and to help plan an extensive seismic and gravity program across this rugged terrain. Stereo, panchro-matic SPOT images and 11 Global Positioning System ground control points were used to create a digital elevation model (DEM) with a 10 meter grid that covered an area about 50 by 100 kilometers," Ellis said.

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 meters.

"These topographic maps were most useful for regional planning and field operations," he said, "because of the varied terrain that consists 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."

Geological application in Yemen involved merging Landsat TM and SPOT imagery to obtain exceptional lithologic discrimination.

"Seismic planning and gravity modeling were significantly improved by digitally draping this enhanced color image over the SPOT/GPS derived DEM," he continued. "This DEM was used to digitally create artificial parallax, permitting stereoscopic interpretation and quantitative determination of structural data such as strike, dip and plunge."

Joining the Big Game

Small, independent oil companies are not as far along on the remote sensing learning curve as the majors, but consultants – or what insiders call the value added community – are an important resource for those smaller firms interested in applying the technology to exploration efforts.

Koger is one of those consultants assisting independents in the application of remote sensing. Like the majors, small companies can benefit from what Koger calls photogeology, but they don't have the internal resources to apply the technology.

That's where outside experts can help.

"Smaller independent firms are typically looking for subtle, smaller targets in more mature hydrocarbon regions," Koger said. "Satellite data for these mature basin applications are best viewed on an array of computer-driven video displays, where interactive control of contrast, brightness, and color is available.

"These systems are the only means by which the entire dynamic range and detail of digital satellite data can be exploited," he continued.

"Cost-effective access to photogeology expertise and computer power" is available from consultants who are up-to-date and maintain image analysis machines, he added.

"Such an operation would be very expensive to keep in-house. Besides, a single photogeology study can develop more leads than most small companies can go through in a year, anyway."

Remote sensing can be valuable in mature basins as well as remote frontier areas, making it an important tool for independents, Koger said.

"I describe these mature regions as a mosaic of information, and the challenge for companies operating in these areas is to add to that mosaic. Remote sensing, more than any other technique, provides the big picture that can tie together all the available data in a mature region and then fill in the empty spaces of the mosaic by highlighting hydrocarbon-related features and providing structural concepts.

"The technique has the added advantage of allowing for samples over time, from today back to 1972, which can be extremely useful in petroleum exploration."

Koger believes the best days are yet to come for remote sensing.

"With any new technology conventional wisdom says there is a 30-year learning curve," he said. "We are about 25 years along that curve, so the next few years should see the technology hit its stride.

"A great deal of oil has been found through the years with the aid of aerial photography, and remote sensing will certainly be even more valuable in the exploration and exploitation of oil and gas." ❑

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.

*Presented at the Ninth Thematic Conference on Geologic Remote Sensing, Pasadena, California, USA, 8-11 February 1993

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.

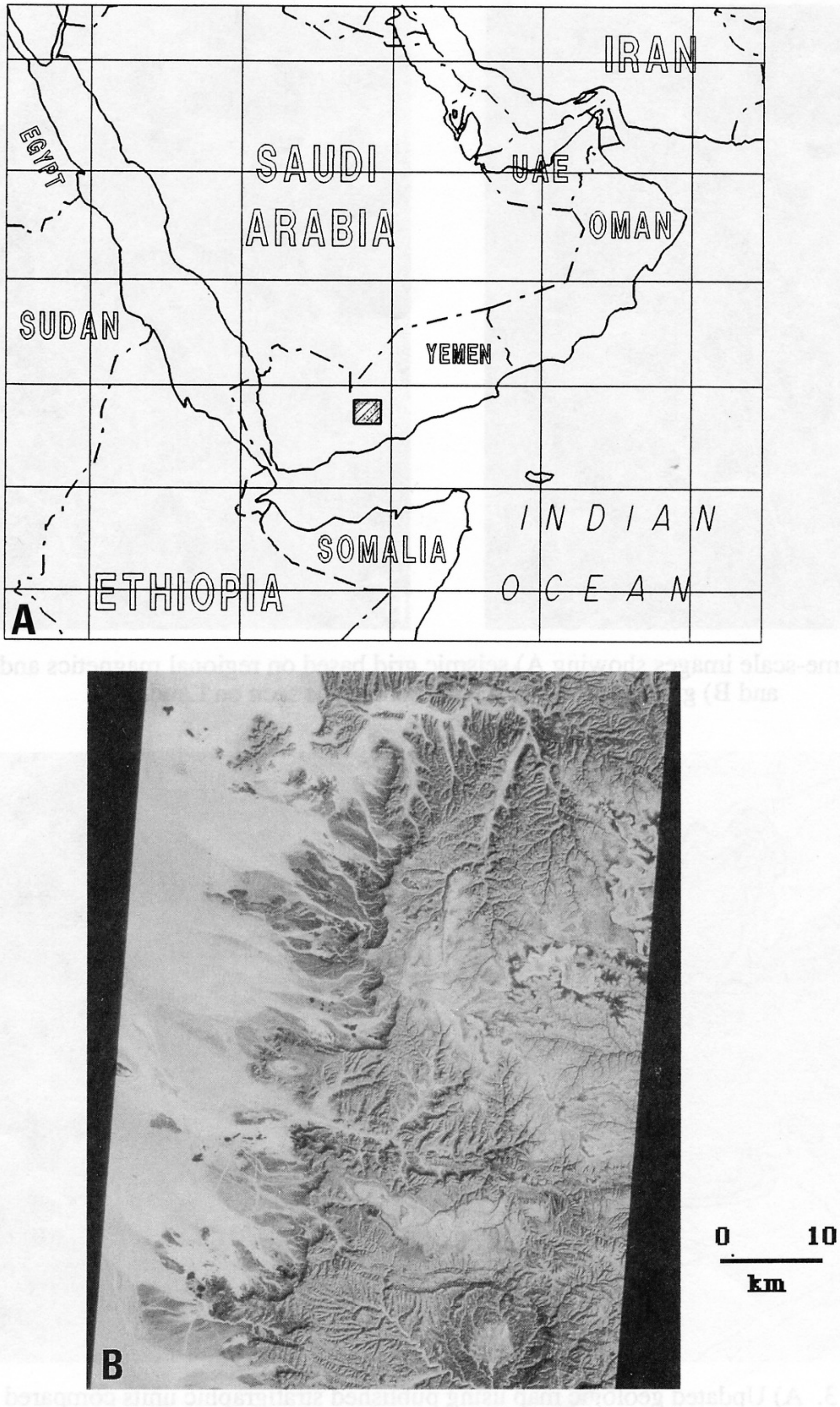

Figure 1. A) Location map of Yemen and B) regional Landsat image (location of image shown on map as shaded area).

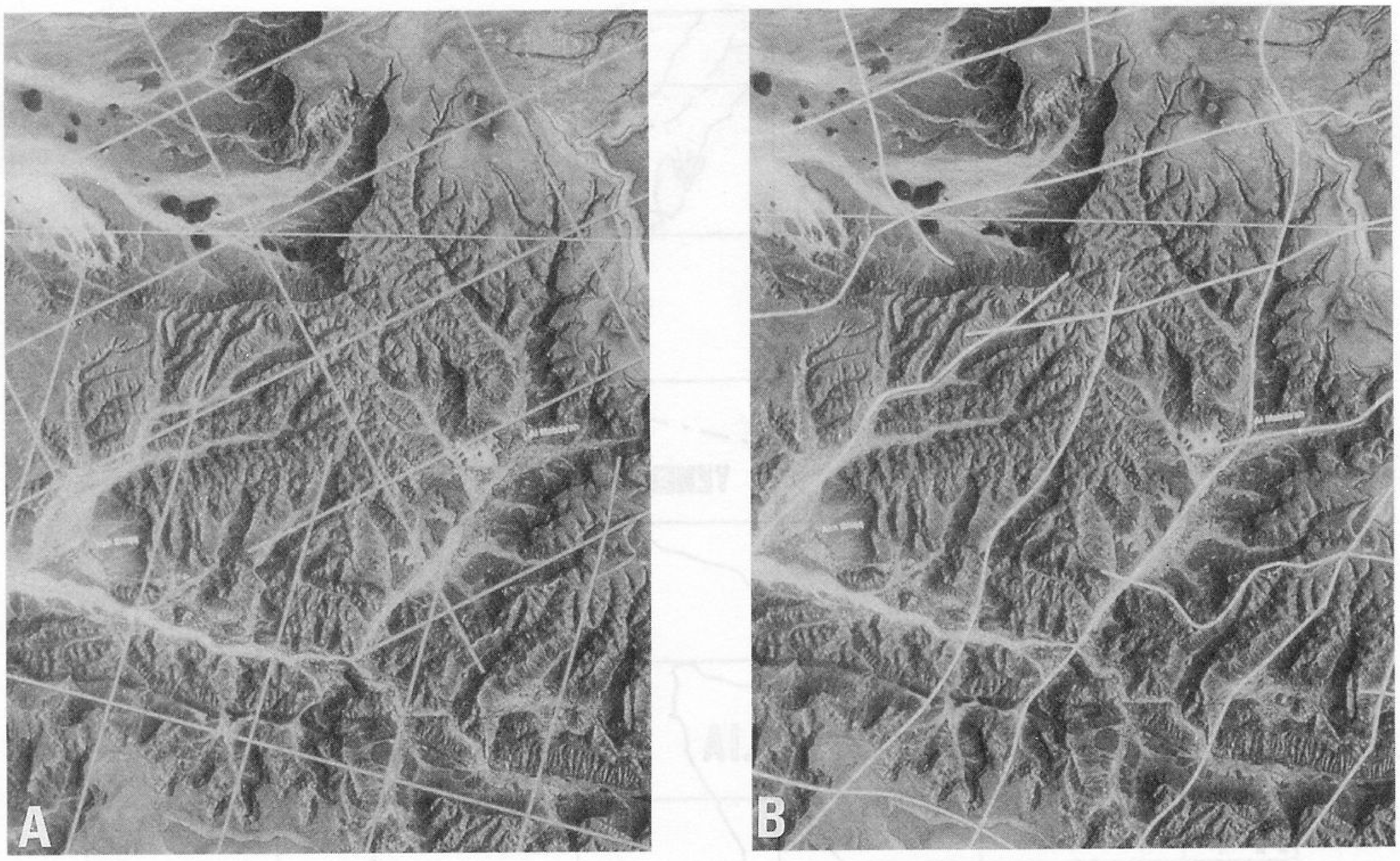

Figure 2. Same-scale images showing A) seismic grid based on regional magnetics and gravity, and B) grid modified by terrain conditions seen on Landsat.

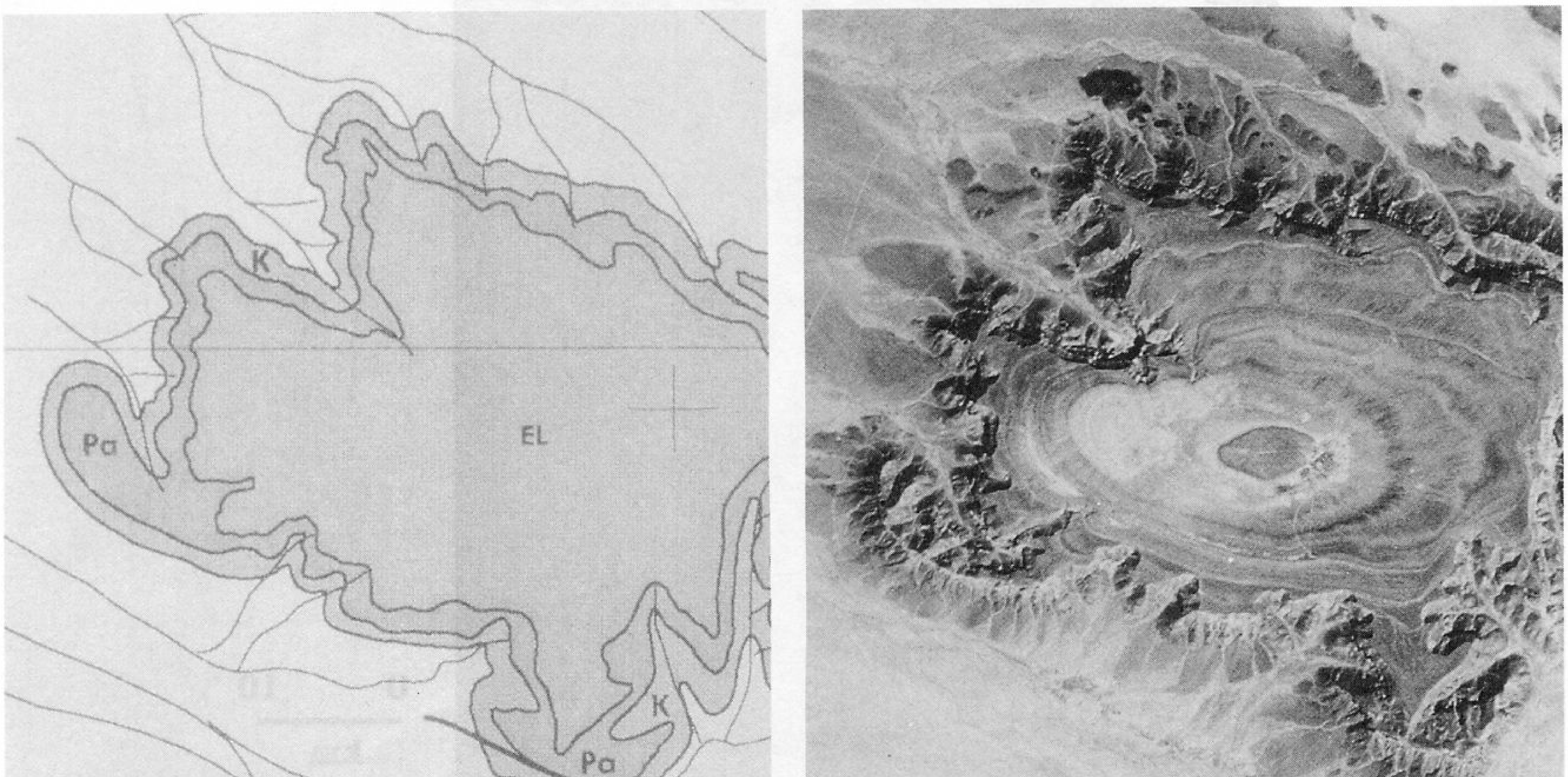

Figure 3. A) Updated geologic map using published stratigraphic units compared to B) additional stratigraphic information available on black & white rendition of digitally merged Landsat TM (742 as RGB) and panchromatic SPOT image. SPOT © 1991 CNES

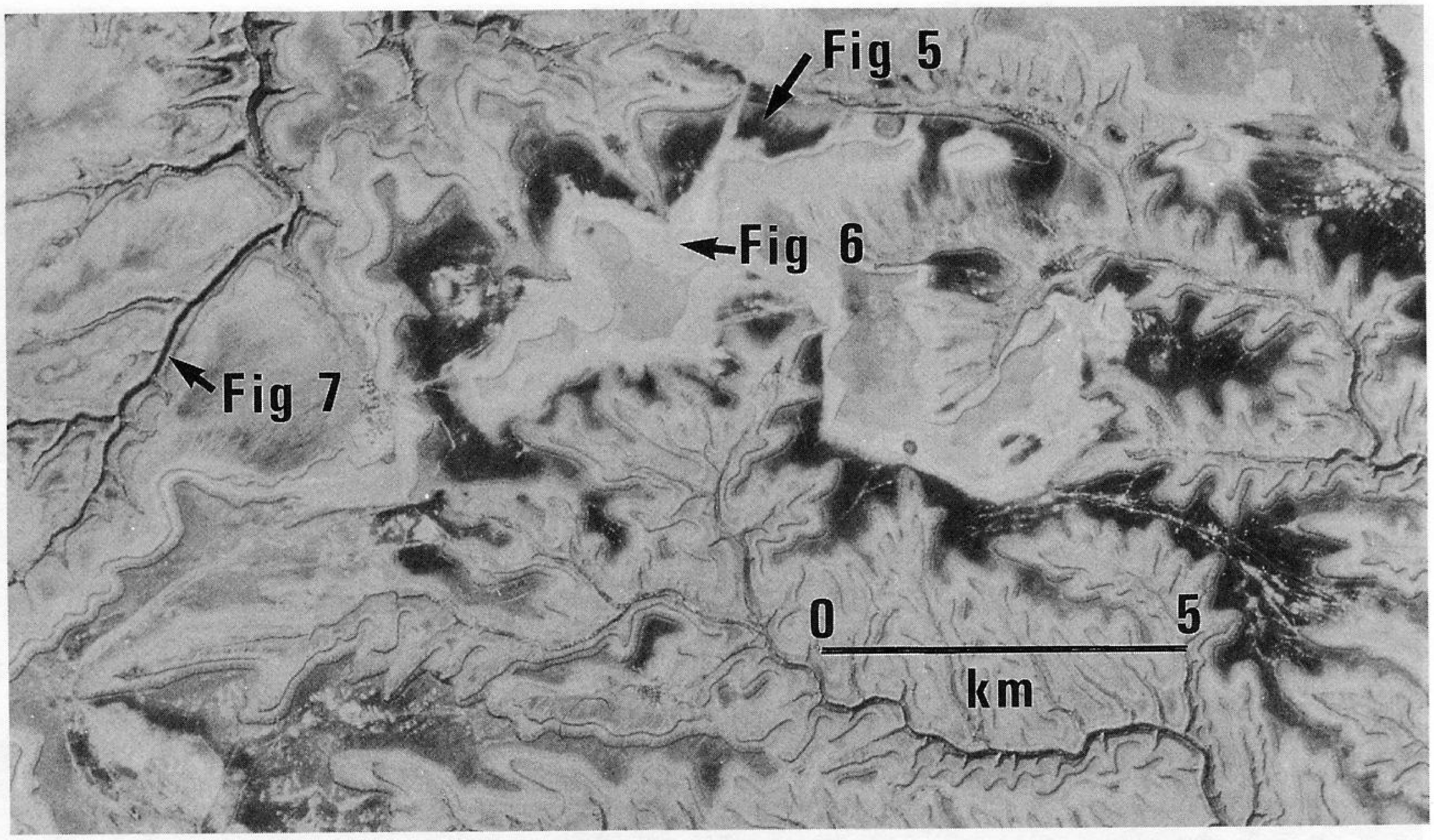

Figure 4. Landsat TM/SPOT image showing typical plateau terrain with arrows indicating field localities shown in Figures. 5-7. SPOT © 1991 CNES

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).

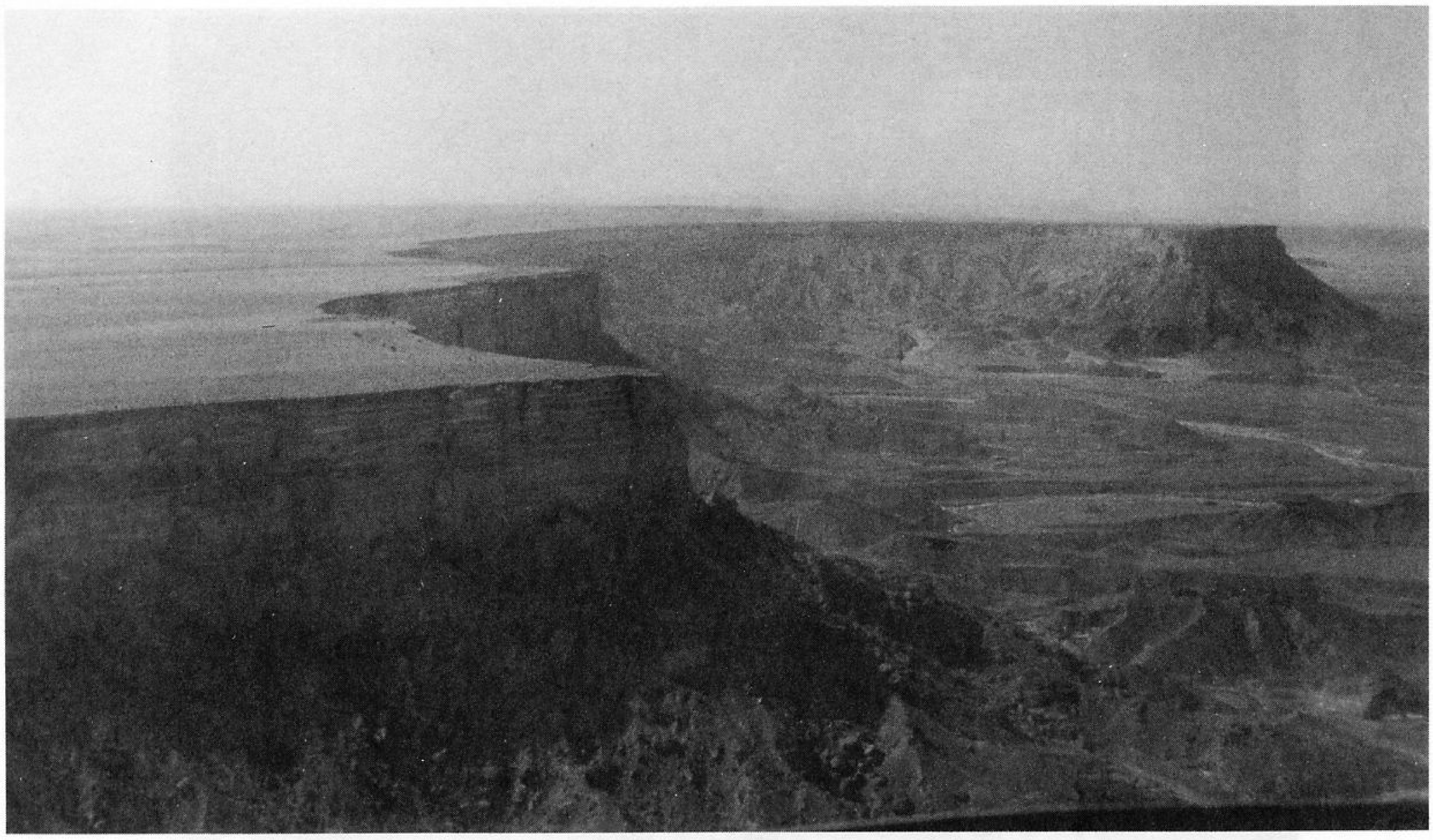

Figure 8. Scenic view looking south at steep cliff termed the "hook" in subsequent figures (see Figure 1 for location).

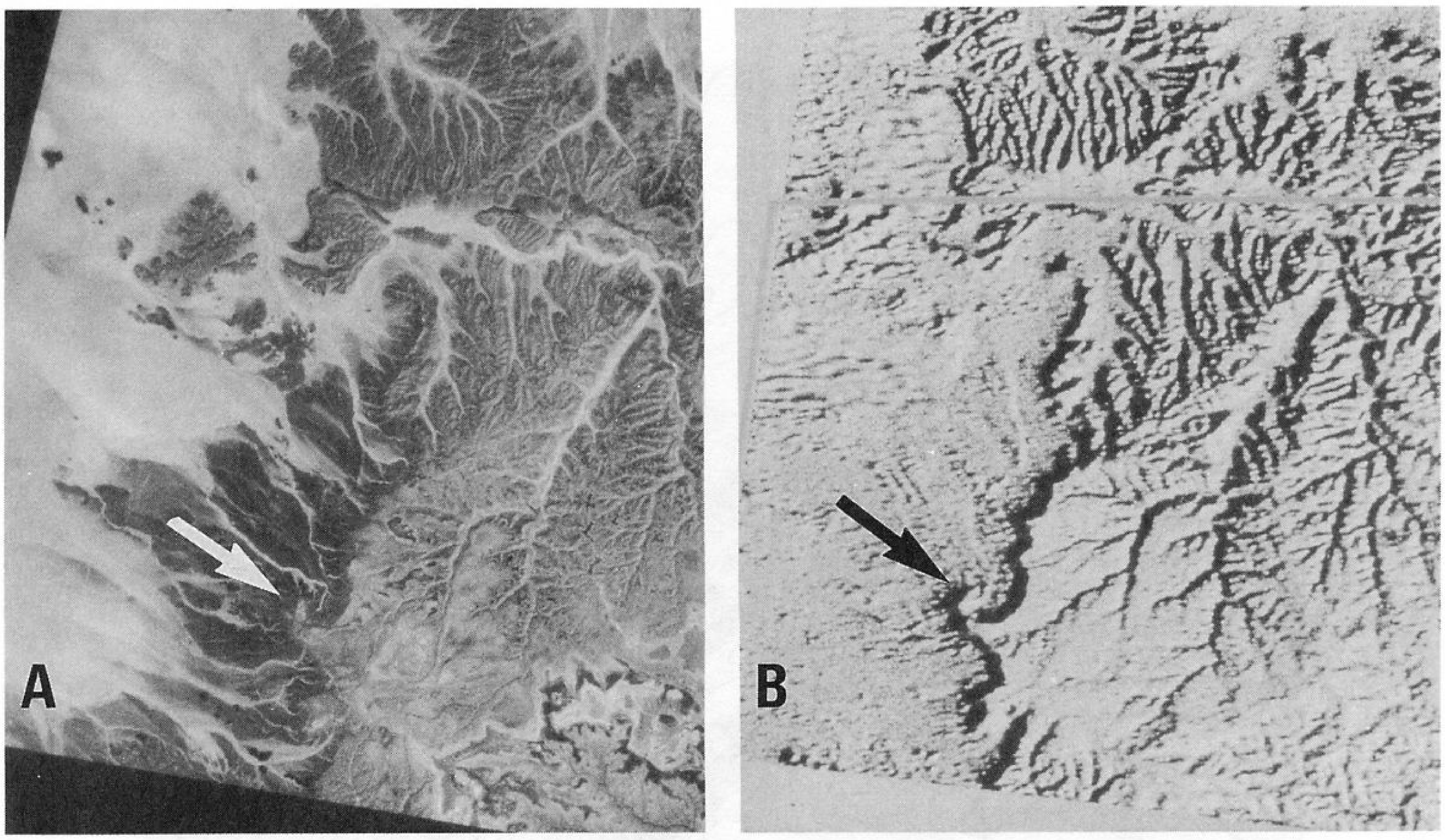

Figure 9. A) Panchromatic SPOT image showing steep cliffs, desert on the right and plateau on the left with same-scale B) DEM artifically illuminated from the east (arrow points to the "hook"). SPOT © 1991 CNES

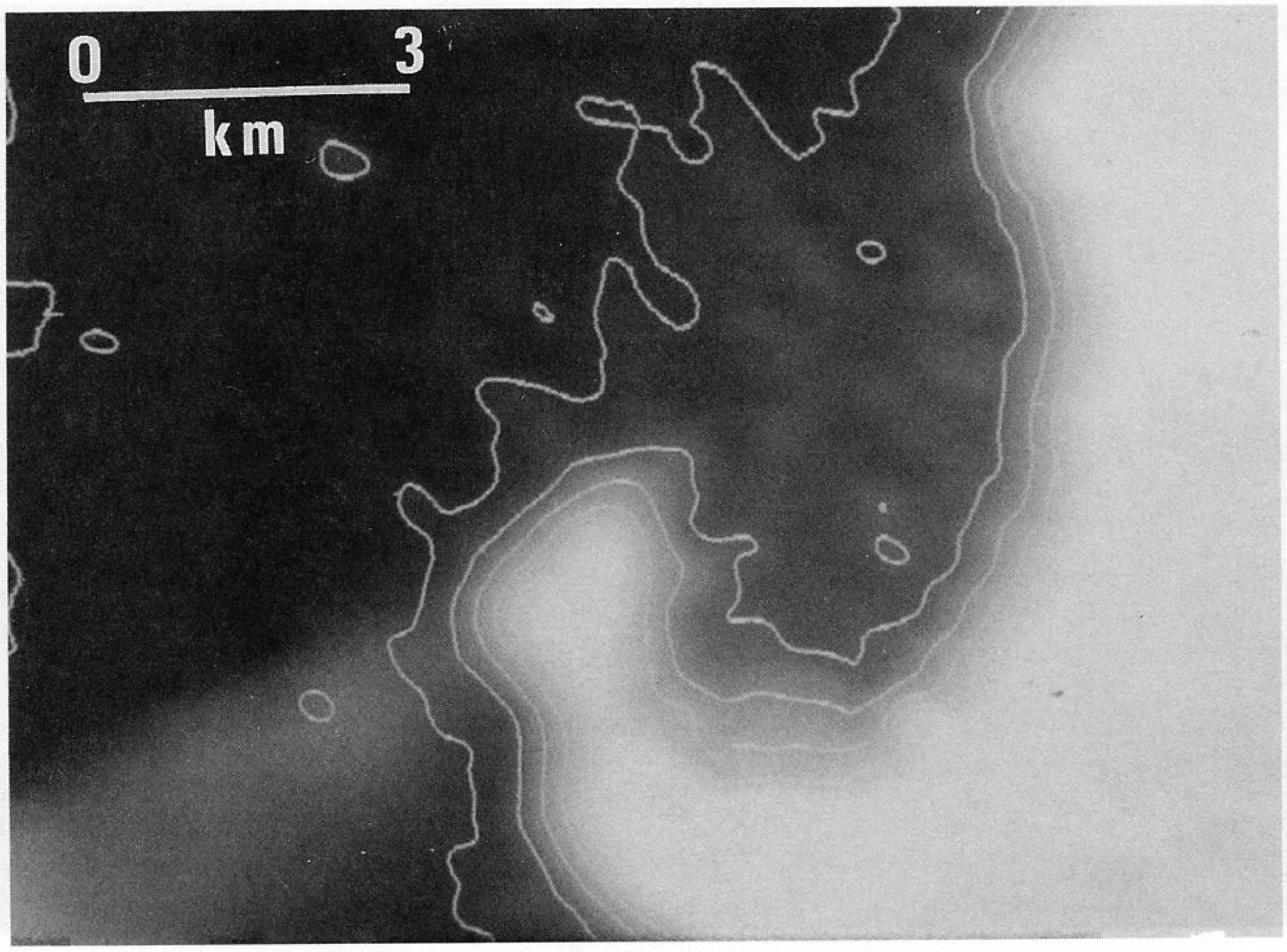

Figure 10. Close-up of DEM over the feature termed the "hook" (same-scale images and maps shown in Figs. 11-13). Contour interval of topographic contours is 100 m.

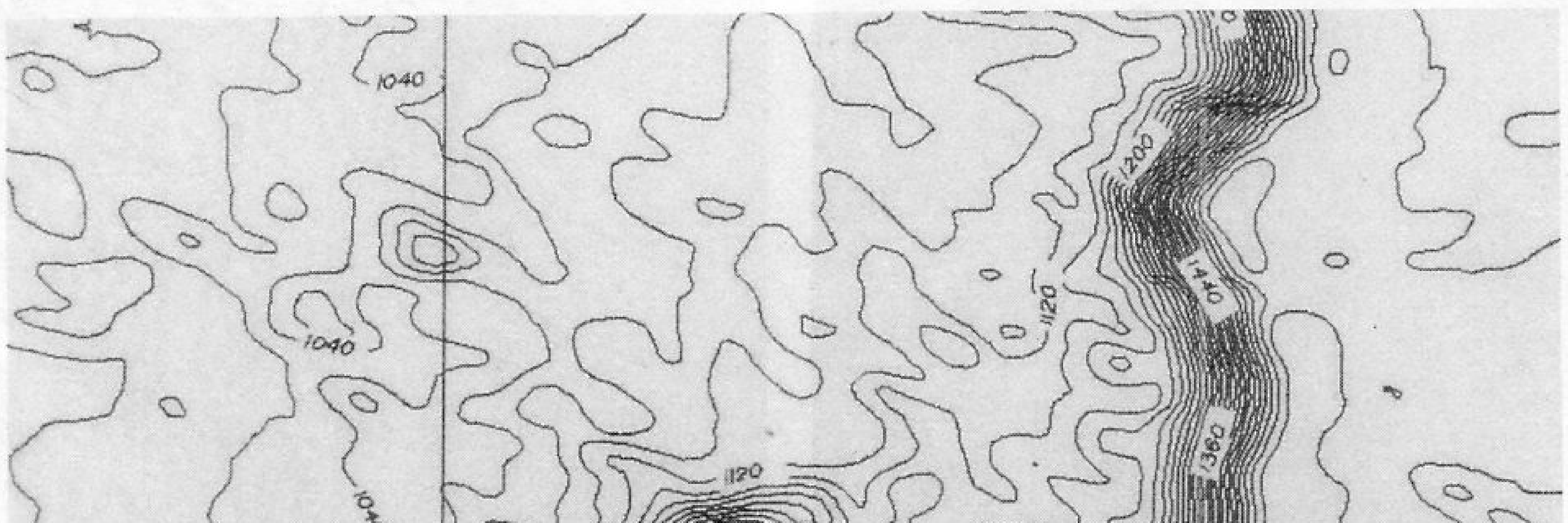

Figure 11. Close-up of topographic map of "hook" with 20 m contour interval

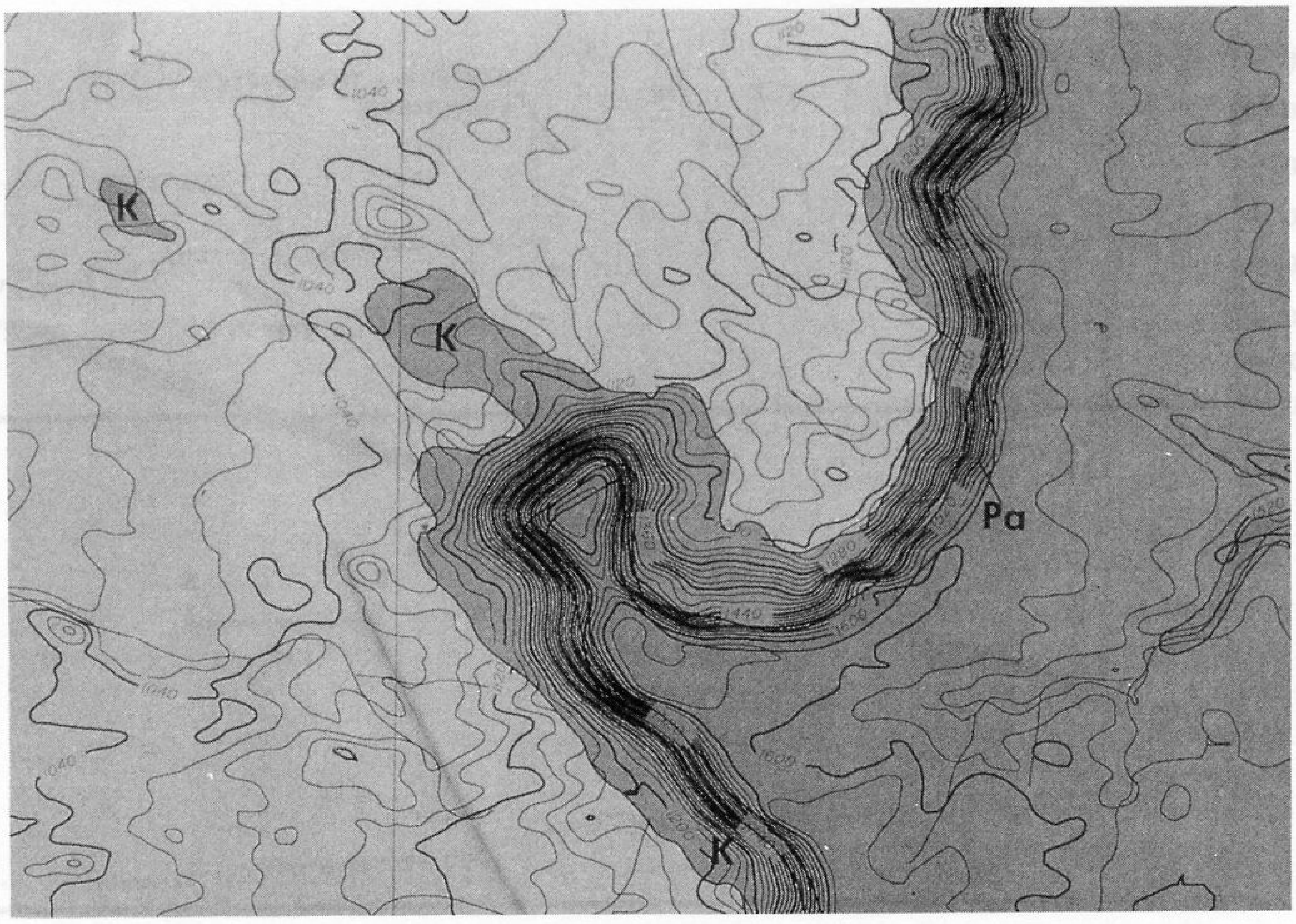

Figure 12. Close-up of the "hook's" topographic map integrated with geologic map.

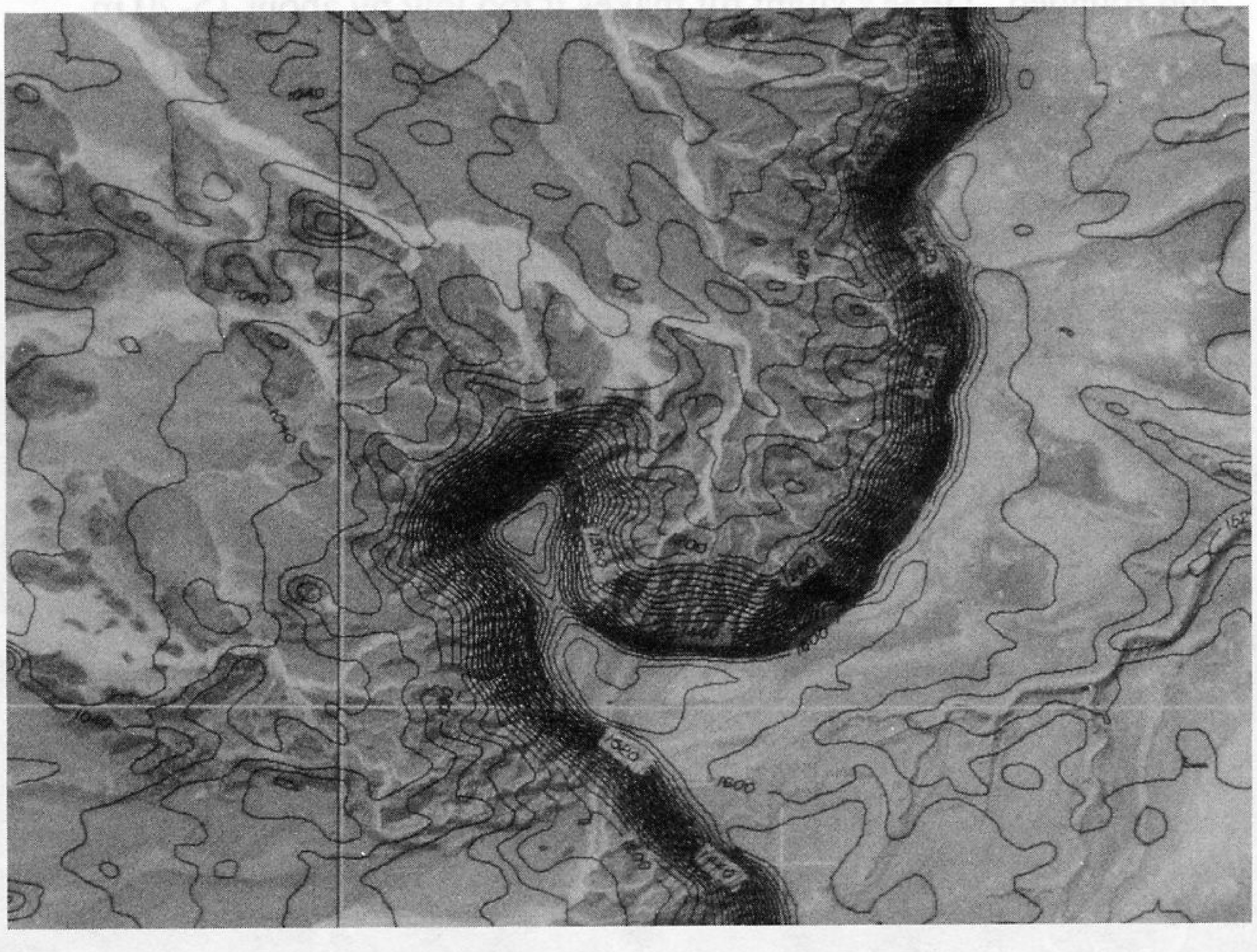

Figure 13. Close-up of the "hook's" topographic map integrated with Landsat TM/SPOT image. SPOT © 1991 CNES

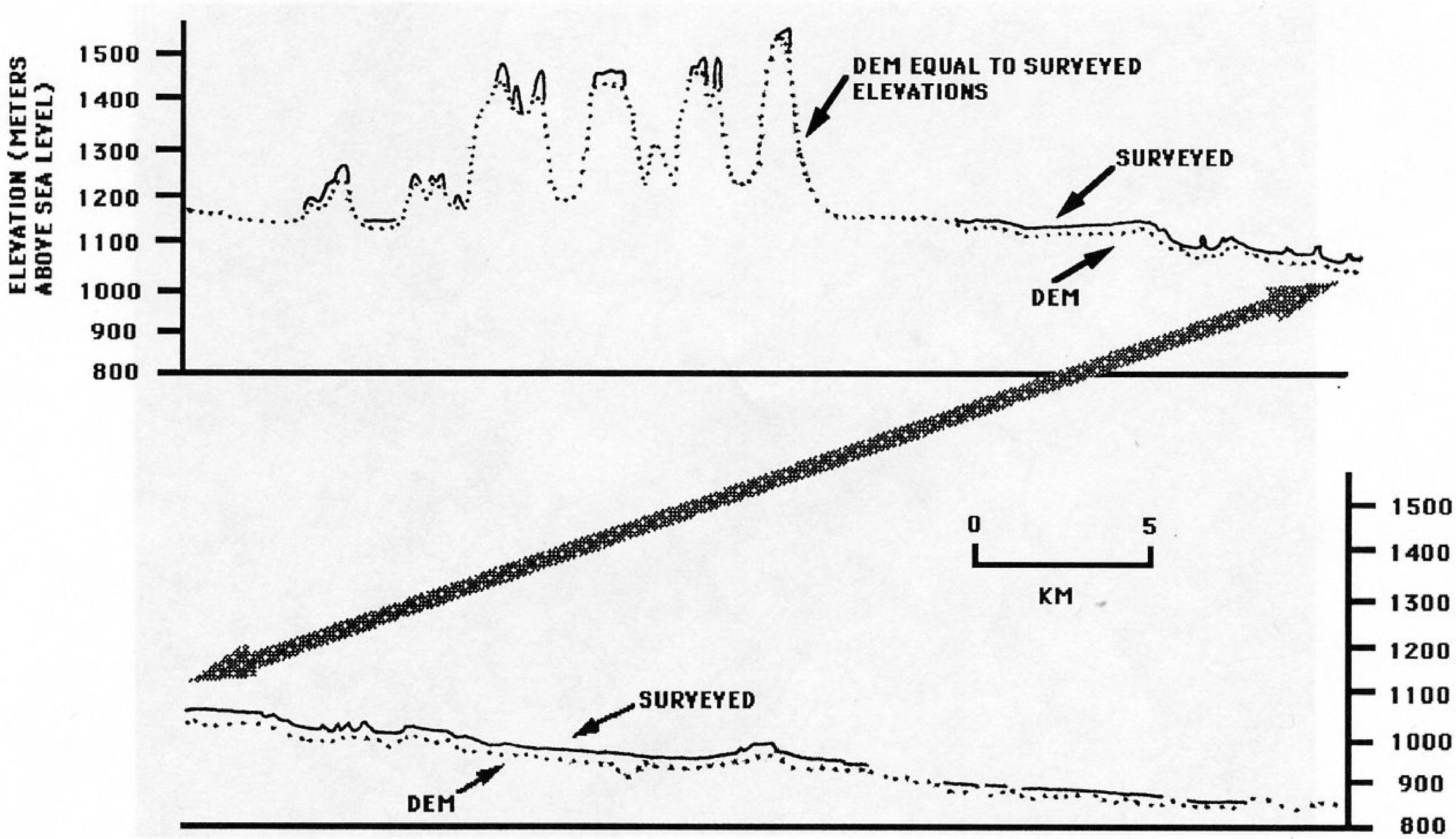

Figure 14. Profile showing difference in meters between DEM and surveyed elevations taken in the field along one seismic line. Agreement is good overall. Peaks are generally lower in DEM and rounded. DEM's slight tilt makes it too low by about 15-20 m.

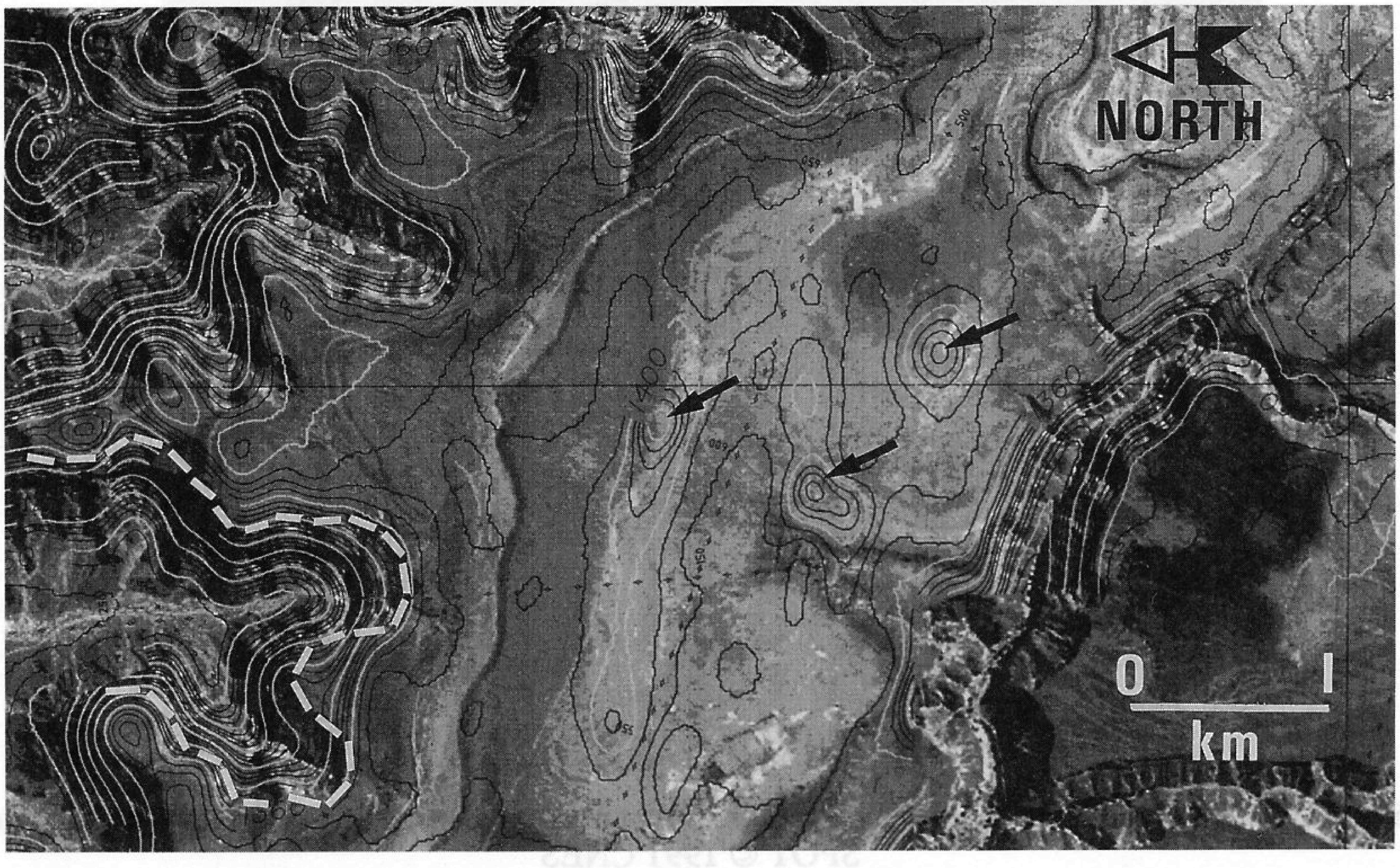

Figure 15. Large-scale plot (generated from 10 m grid and contoured at 10 m interval) showing problems with rounded cliffs (dashed line outlines true edge of cliff as seen on SPOT stereo pair) and with random cones and depressions on flat areas. Problems are less evident on smaller-scale maps and DEM's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