REMOTE SENSING TECHNOLOGY FOR GEOLOGIC MAPPING AND FIELD OPERATIONS, COLOMBIA*

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ABSTRACT

Landsat TM and SPOT imagery, airborne radar (SAR), and aerial photographs have been integrated successfully with field work to improve geologic mapping and field operations along the western and eastern flanks of the Eastern Cordillera, south of Santafé de Bogota, Colombia. Along the western flank, TM imagery was used for attempting to corrrect geologic interpretations of SAR images because the mountainous terrain on the SAR images was distorted because of radar layover. Structural features first recognized on the SAR imagery included: a) the surface trace of a thrust fault, b) an overturned anticline, and c) a thrust structure produced by either wedging or nappe emplacement. These surface expressions of structures were substantiated during field mapping and a subsequent seismic survey. Aerial photographs were used to determine dips, resolve questions about the geology, and construct a 1:50,000 topographic map. In the eastern area of interest, a panchromatic SPOT image was used as a cartographic base. SPOT provided excellent information on roads, land use, and forest conditions. Where cloud cover degraded SPOT, SAR images were utilized for planning. As expected, SAR images provided excellent information on geologic structure and lithology across the mountainous project area. Integration of images and maps was done manually in the western area, while integration of these data in the eastern area was done digitally within a workstation environment. Although in mountainous terrain digital integration of unrectified SAR images was difficult, mapping in a workstation environment offered significant advantages, especially in a long-term field project where interpretations and maps were continually being modified and updated.

1.0 INTRODUCTION

Chevron Petroleum Company of Colombia has been actively using remote sensing technology, aerial photographs, and field work to improve geologic understanding and field operations within Colombia (Ellis and Dekker, 1988). This paper presents case histories of recent activity along the flanks of the Eastern Cordillera (Figure 1), in an exploration license on the western flank ("Sumapaz") and in an active license along the eastern flank ("Rio Blanco"). The Rio Blanco acreage is on trend with the recent, giant Cusiana discovery.

Both Sumapaz and Rio Blanco are characterized by rugged mountainous terrain, extensive cloud cover, and areas of dense vegetation (Figure 2). Only regional geologic maps were available from published sources when both projects were initiated. Landsat MSS images from the mid-1970's had been previously processed for regional mapping, but their ground resolution was insufficient and they were too out-of-date to support extensive field operations

2.0 MAPPING THE SUMAPAZ AREA

Sumapaz, the area along the western flank of the Eastern Cordillera (Figure 1), was evaluated with Landsat TM, stereoscopic radar flight strips, and aerial photographs. The license covers approximately 1800 km^2 with topographic elevation increasing from 500 m along the western margin to 3600 m along the eastern portion. Sumapaz lies approximately 30 km east of the Magdalena River in the Upper Magdalena Basin.

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Landsat TM imagery was used to check and update a CAD basemap that was digitized from published topographic maps. The Landsat image was acquired in 1988 and was extensively processed to maximize color differentiation, emphasize topography, and penetrate haze (Figure 3). Color saturation was increased through the IHS transformation. A black & white image emphasizing topography was created with principal components transformation. A final color composite was generated with band 7, principal component 1, and band 5 as red, green, blue. This combination displayed vegetation as shades of green, with the most dense forest as dark green. This TM color composite was easy to understand in the field and proved useful for planning and estimating difficulty and costs of field operations. For example, in the eastern portion of the Sumapaz license, the Landsat showed where forest cover no longer was a logistical problem as it clearly displayed where the terrain rose above treeline. In addition, clear-cut areas, agricultural plots, and burn areas were distinctly shown with brownish-red colors. There were no major roads in the area, however, larger villages were displayed as light brown areas. For geologic interpretation, the color Landsat was useful for mapping the accurate location of resistant ridges and hogbacks. TM imagery could not be uniquely correlated with lithology or stratigraphy, but was useful for recognizing relative variations in lithology within local areas.

Airborne radar data were acquired in 1987 from a speculative survey by Intera Technologies. The flight lines were North-South and the terrain was illuminated with an East-looking radar beam. The data were collected with a ground resolution of 12 m. Only 1:100,000 and 1:50,000 prints of stereoscopic flight strips were used in this project. These were manually spliced together to form a regional mosaic (Figure 4).

No digital correction was made to the SAR data to compensate for layover distortions due to topography. To minimize radar distortions, a basemap overlay was manually shifted while interpreting the SAR plots. The locations of rivers and crests of resistant ridges (taken from the Landsat) were plotted on the overlay and these provided the control for this approximate cartographic correction. Geologic strike and dip were initially estimated across the field area from stereoscopic interpretation of overlapping SAR flight strips. Lithology (where field work or published maps were available) was interpreted from the SAR flight strips. The advantage of SAR imagery compared to multispectral satellite imagery for geologic mapping in cloud-prone areas such as Colombia is clearly shown on Figures 5 and 6.

Structural features first recognized on the SAR imagery include: a) the surface trace of a thrust fault, b) an overturned anticline (Figures 5-8), and c) a thrust structure produced by either wedging or nappe emplacement. These surface expressions of structures were substantiated during field mapping and a subsequent seismic survey (Figure 8).

Black & white aerial photographs (Figure 9) were available for much of the Sumapaz area. These stereoscopic photographs were used to determine dips, resolve questions about the geology, and construct a 1:50,000 topographic map (Ellis and Narr, 1993). Bedding attitudes determined from air photos and field work were used to constrain seismic interpretation (Figure 10).

Several iterations of field mapping, reinterpretation of Landsat, SAR, and aerial photographs, and redrafting resulted in a final 1:50,000 geologic scale map of Sumapaz. The amount of redrafting was substantial as overlays at 2 scales were utilized by several earth scientists for geologic interpretation during the project. This procedure led to a very high error rate that required a substantial effort to repair. However, compared to one of the published maps available at the beginning of this Sumapaz mapping project (Figure 11), the new geologic map generated from this integrated project was more accurate and useful for supporting exploration (Figure 12).

3.0 MAPPING THE RIO BLANCO AREA

Terrain in the Rio Blanco area increases in elevation from 600 m in the east to 2400 m in the west. The mapping effort along the eastern flank benefited from a high resolution, panchromatic SPOT image that was acquired in 1992 for verifying well locations in oil fields operated in the adjacent Llanos Basin by Chevron Petroleum Company of Colombia. This SPOT image covered the mountainous area of interest and was used as the cartographic base. The SPOT image was an excellent source of information on land use and the transportation network, and was used extensively for planning field operations except where clouds obscured the terrain (Figure 13). Within the mountains there was little geological structural information visible on the SPOT image due to high sun angle (minimum shadowing) and excessive cloud cover.

Airborne SAR data were acquired in 1992 and were used with SPOT for planning seismic operations. The SAR flight lines were North-South with the terrain illuminated from the East. The data were collected with 12 m pixels. As expected, SAR images provided excellent information on geologic structure and lithology. Digital SAR mosaics were acquired from the contractor (Figure 14).

The SAR mosaics and individual flight strips were loaded into an image processing/interpretation workstation as raster images and registered to the SPOT image. No attempt was made to cartographically corrrect the SAR for distortion due to topography. Image-to-image registration was difficult because of a lack of visible control points on the SAR and SPOT imagery, especially in the mountains. Excessive shadowing obscured the valleys on the SAR images and clouds covered many of the crests on the SPOT images (compare Figures 13 and 14). After co-registration, the airborne and satellite images were rectified to a Transverse Mercator projection using visible well pads with known Latitude/Longitude locations. Proposed seismic line locations, oil seeps, tar sand deposits, national park boundaries, wells, and major roads were embedded into the images (Figure 15). These informative image maps were delivered to the field at scales to 1:50,000 to assist in planning field operations, environmental baseline studies, and geologic mapping. Some seismic line locations were shifted after evaluation of the up-to-date imagery , resulting in significant cost savings. Within the workstation environment, structural interpretations of distorted SAR images were digitized into more correct cartographic positions using the co-registered SPOT images as a base.

A published geologic map and the project's geologic map (based on new geologic observations in the field) were digitized and registered to a Transverse Mercator map projection. On the workstation these geologic maps were displayed and compared with co-registered raster images (SPOT and SAR imagery) and vector maps (proposed seismic line locations, new image interpretations, etc.) to facilitate identifying, documenting, and changing inconsistencies. As new geological and geophysical information came in from the field, interpretation and/or plannning changes were easily entered into the CAD mapping files. Replacement maps and updated interpretations were continuously and efficiently generated during the life of the project.

4.0 CONCLUSIONS

Landsat TM, SPOT, and SAR are effective sources of up-to-date information for supporting field operations, geologic mapping, and planning of oil and gas exploration. When SAR images are not corrected for distortions due to topography, digital integration with satellite images and maps is difficult. Co-registration of raster images and vector maps in a workstation environment offers significant advantages, especially in a long-term field project where interpretations and maps are continually being modified and updated.

5.0 ACKNOWLEDGEMENTS

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6.0 REFERENCES

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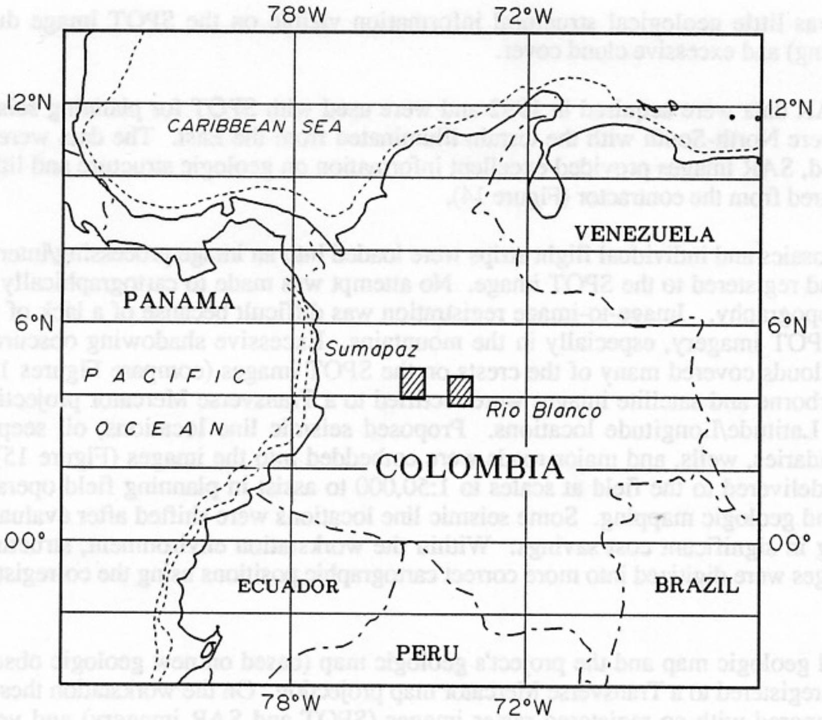

Figure 1. Location map of Colombia showing Sumapaz and Rio Blanco areas

Figure 2. Ground view of Sumapaz, Colombia

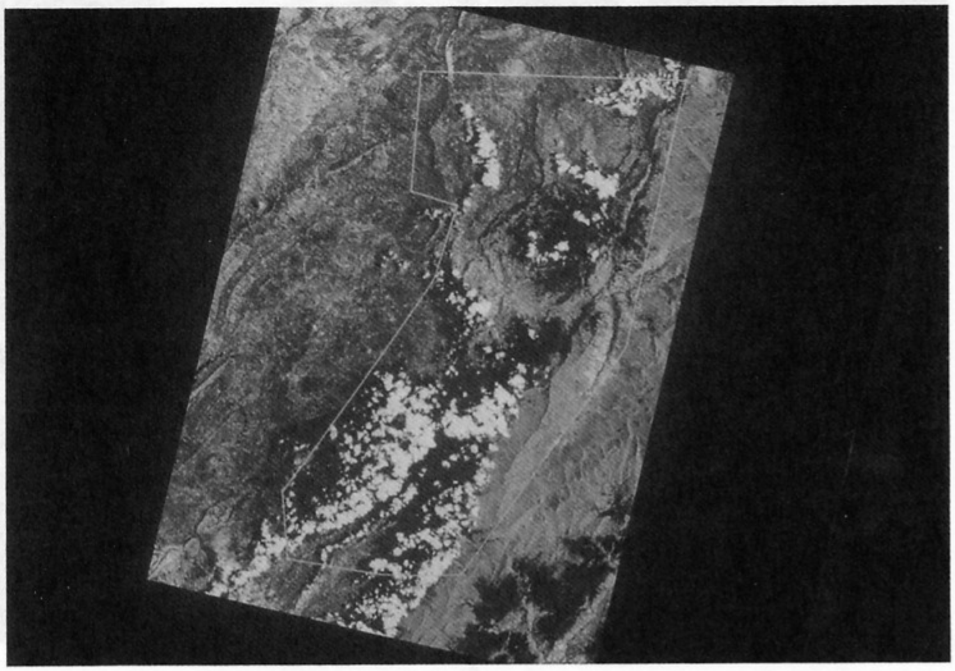

Figure 3. Landsat TM image of Sumapaz showing exploration license boundary

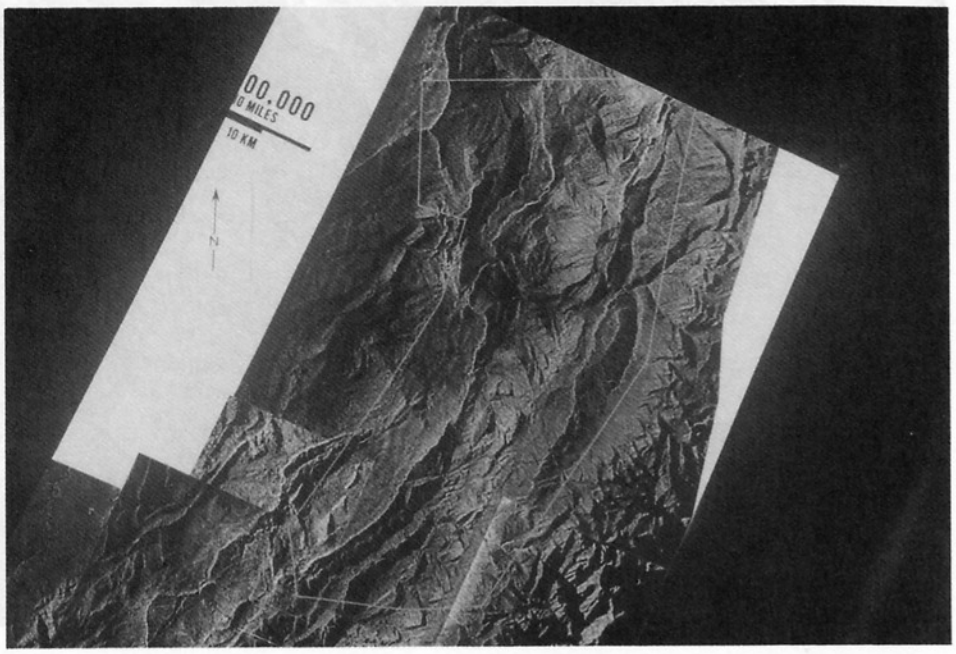

Figure 4. Airborne SAR image of Sumapaz showing exploration license boundary

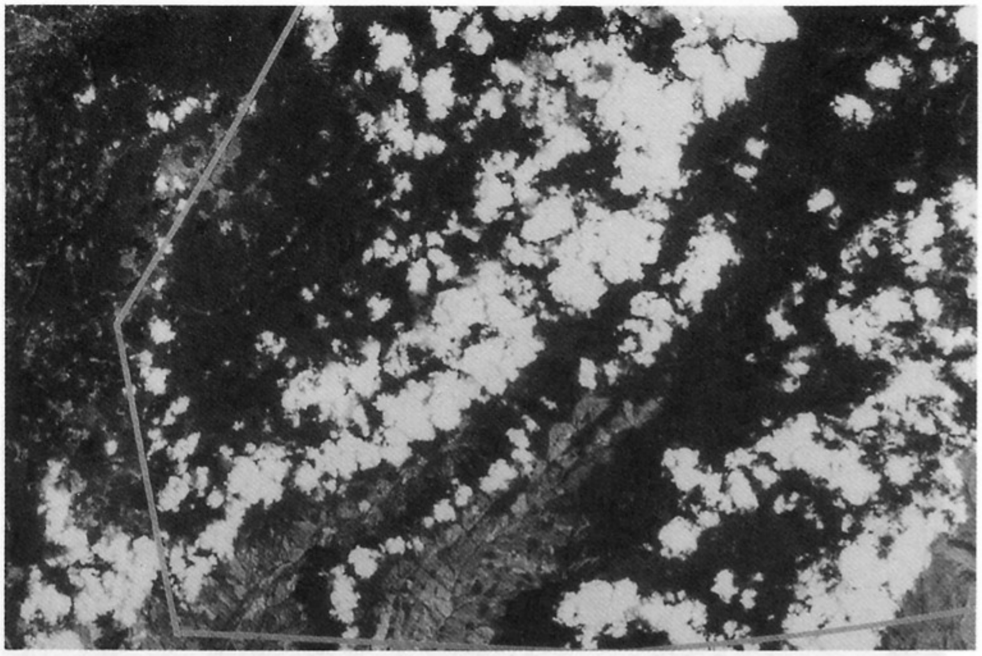

Figure 5. TM image of Sumapaz subarea - used for basemap except where cloud cover excessive (same scale and area as Figures 6 and 7)

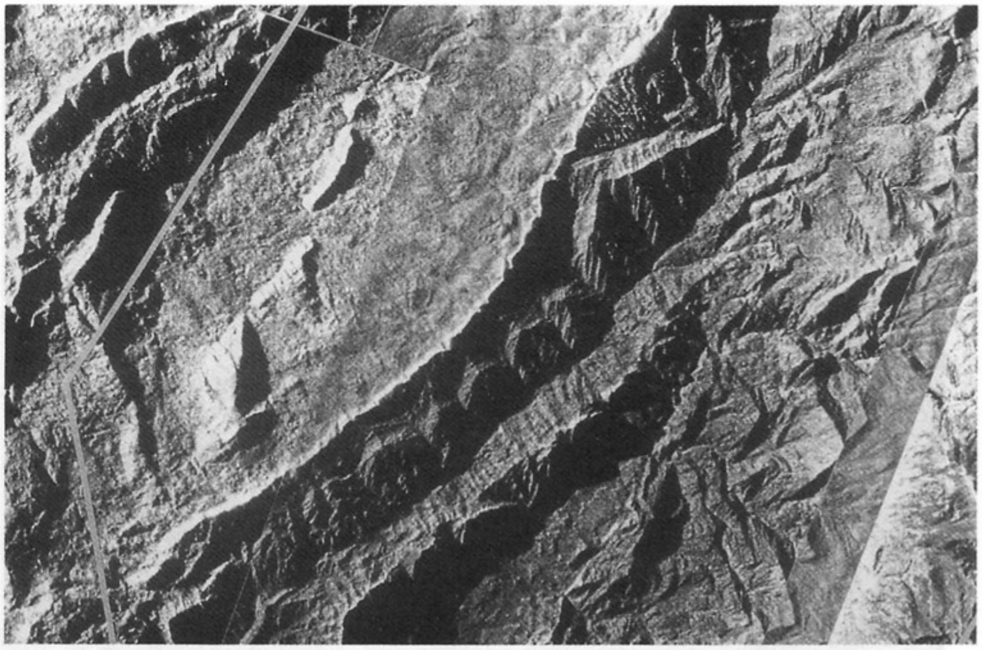

Figure 6. SAR image of Sumapaz subarea showing entire ground area - superior for geologic mapping (compare to Figure 5)

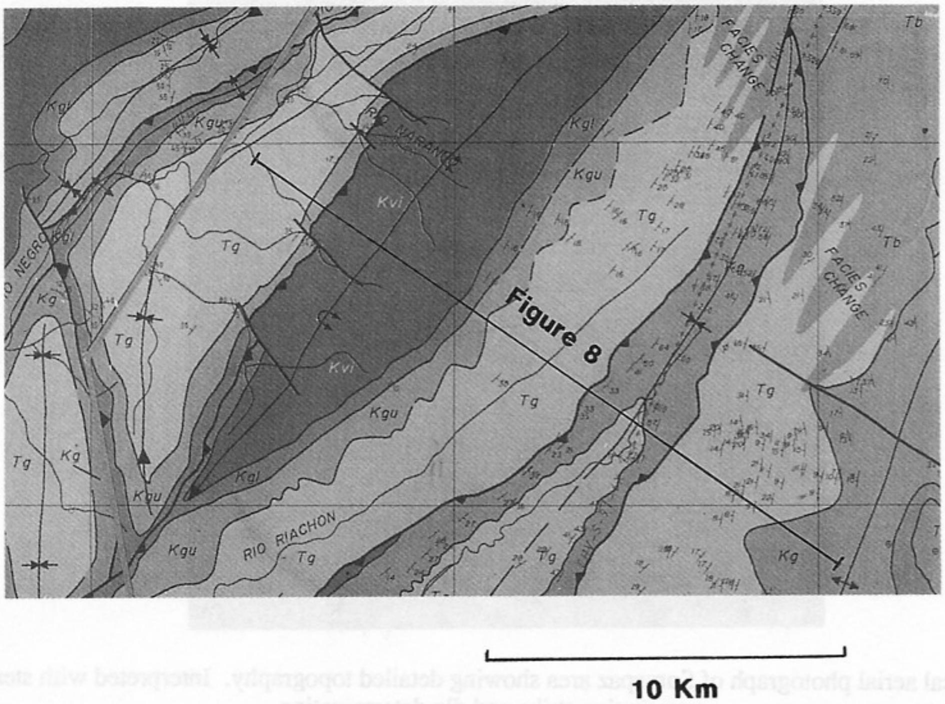

Figure 7. Geologic interpretation of Sumapaz subarea based on interpretation of SAR and aerial photographs and field work (see Figure 6)

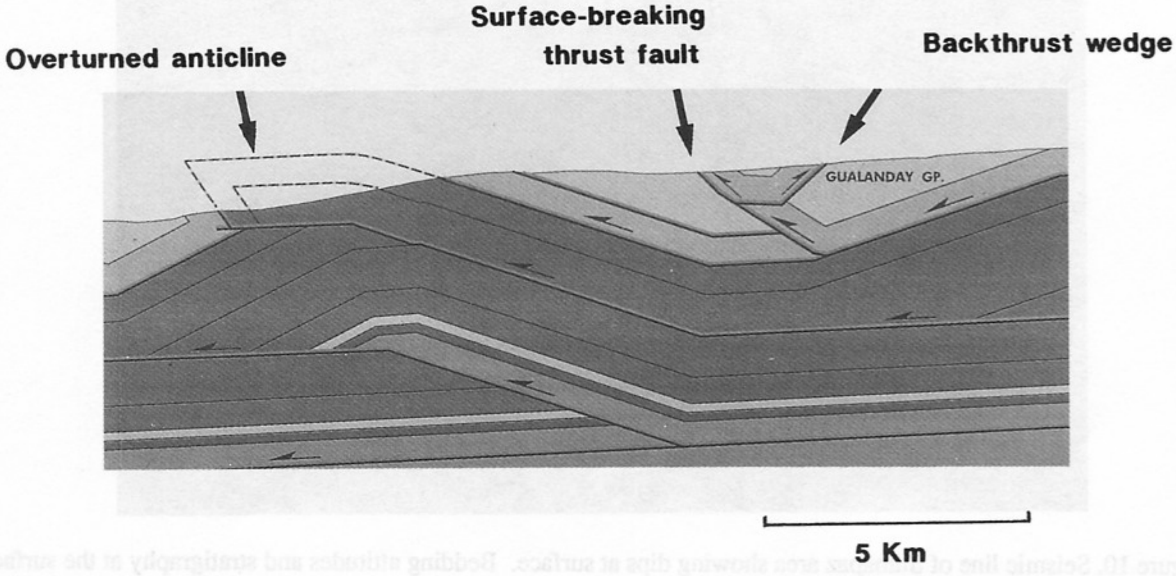

Figure 8. Cross-section of Sumapaz subarea (see Figure 7 for location) where surface geology based on interpretation of SAR and aerial photographs and field work

Figure 9. Typical aerial photograph of Sumapaz area showing detailed topography. Interpreted with stereoscope for quantitative strike and dip determination.

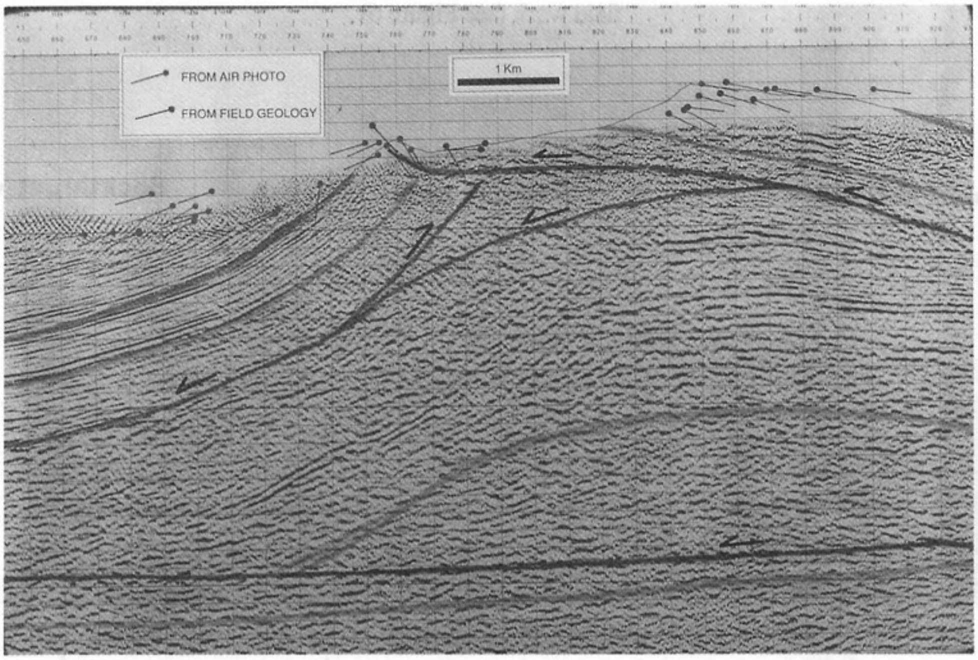

Figure 10. Seismic line of Sumapaz area showing dips at surface. Bedding attitudes and stratigraphy at the surface determined from remote sensing, air photos, and field work were used to constrain seismic interpretation.

Figure 11. Example of geologic map available at the onset of the Sumapaz Mapping Project (compare to Figure 12)

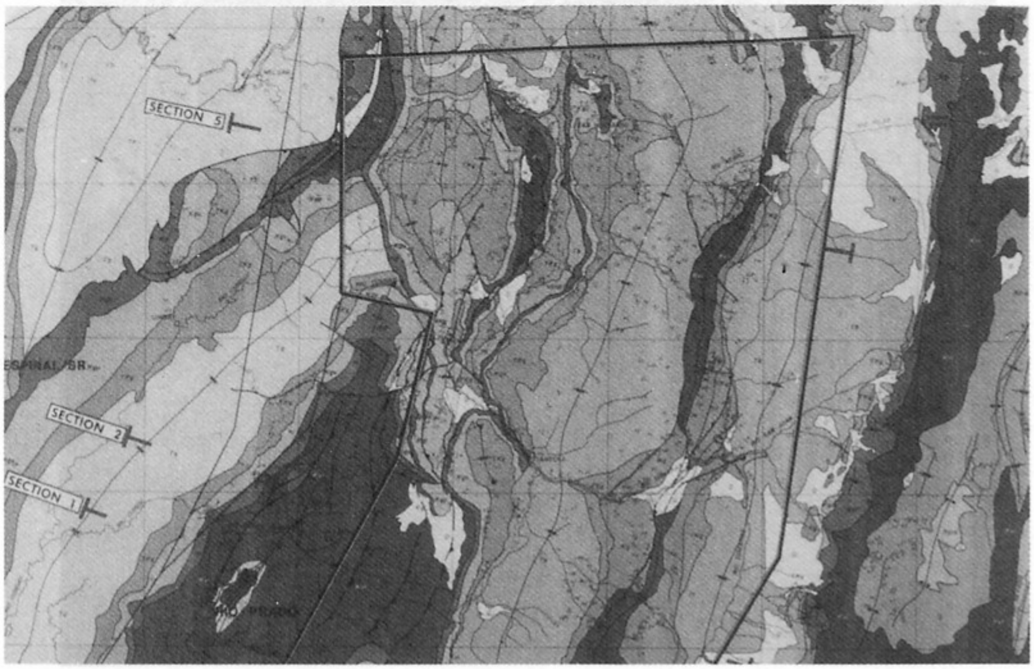

Figure 12. New map generated of Sumapaz using remote sensing technology, aerial photographs, and field work

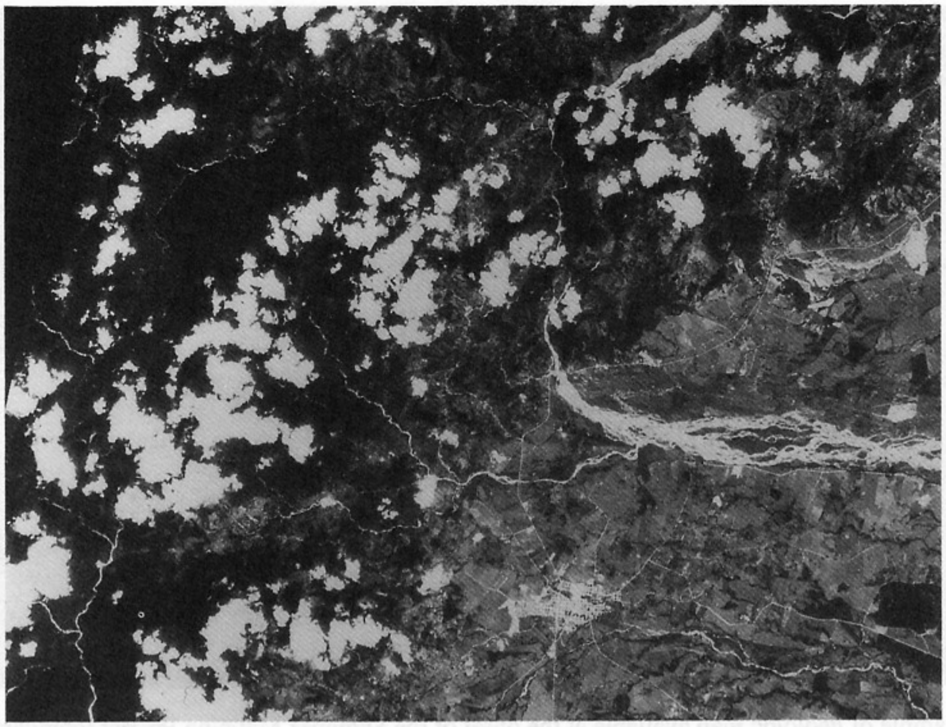

Figure 13. Panchromatic SPOT image of Rio Blanco subarea (eastern flank of Eastern Cordillera) showing excellent delineation of roads, towns, land use, and forest cover. Clouds degrade usefulness for mapping in mountains.

Figure 14. Airborne SAR image of Rio Blanco subarea showing excellent definition of geologic structure. Radar shadow cast by rows of trees growing along roads delineates transportation network in lowlands.

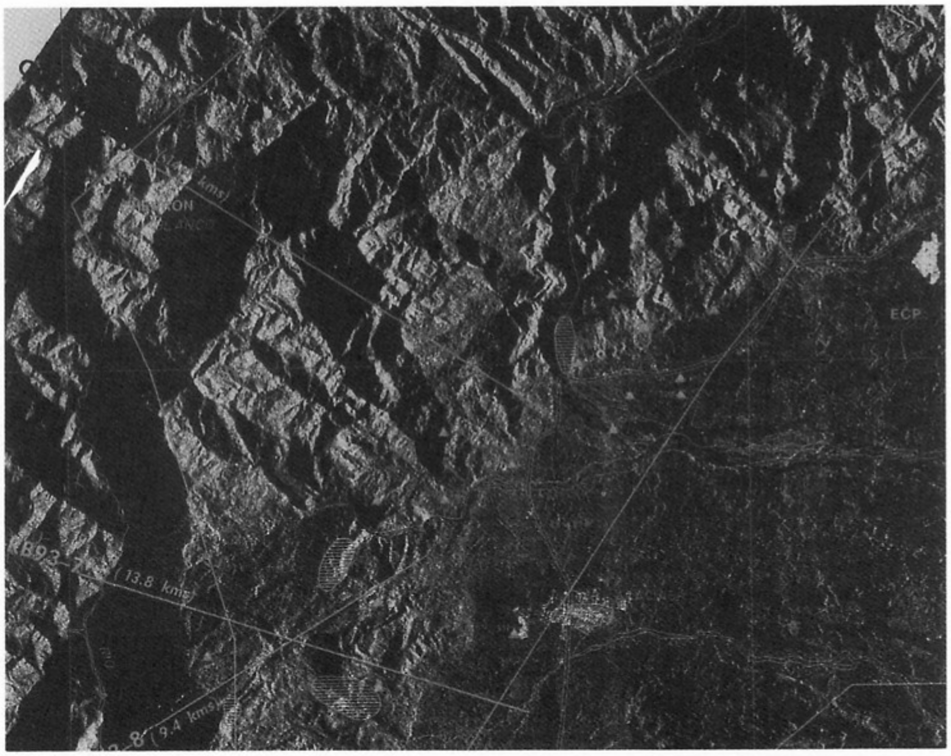

Figure 15. Workstation view of digital integration where SAR image superimposed with seismic program.