

EVALUATION OF USE OF REMOTE-SENSING IMAGERY IN REFINEMENT OF GEOLOGIC MAPPING FOR SEISMIC HAZARD ZONING IN NORTHERN LOS ANGELES COUNTY, CALIFORNIA

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KEY WORDS: Remote Sensing, Seismic Hazard Zoning, Geologic Mapping, Hyperspectral, Multispectral, VNIR, SWIR, TIR

ABSTRACT:

The California Seismic Hazards Mapping Act of 1990 directs the California Geological Survey (CGS) to delineate seismic hazard zones of required investigation for earthquake-induced ground failures - specifically, liquefaction and seismically triggered landslides. To date, more than 100 official Seismic Hazard Zone maps have been released, covering 200 cities and unincorporated areas in ten counties in California. We use both remote sensing and GIS data layers in the production of the Seismic Hazard Zone maps. One of the most important primary data layers is geology. The quality and accuracy of existing geologic maps vary, however, because of differences in purpose of mapping, scale or levels of detail, presence or absence of standard nomenclature, and types of map projection/registration. To address this problem, the CGS Seismic Hazard Mapping Program (SHMP) conducted a study in the sparsely to highly vegetated terrain of northern Los Angeles County to determine if remote-sensing imagery could improve or enhance the geologic information being used in seismic hazard zoning. We evaluated imagery that included ASTER, Landsat 7 ETM, SPOT, USGS DEM and DOQQ, and airborne Interferometric SAR (IFSAR). All imagery was processed and/or observed on ENVI, ILWIS, Intergraph MGE, GeoMedia, and MapInfo. The evaluation was based on application of different algorithms to accomplish various geologic “tasks” such as: 1) discrimination of geologic contacts between bedrock and unconsolidated Quaternary deposits, 2) recognition and delineation of landslides, 3) confirmation of previously mapped geologic contacts, and 4) verification of cartographic registration of digital geologic maps. We found that applicability and utility of single remote-sensing images for these tasks varied considerably, but the use of combinations of multiple images from different sensors significantly increased the utility of the imagery for our mapping/zoning process. The overall results of the evaluation are presented in tables that rate the various sensors and algorithms.

1. INTRODUCTION

The successful production of CGS Seismic Hazard Zone maps relies heavily on the accuracy of the geologic map layer that depicts the spatial distribution of geologic units. It is imperative that contacts between bedrock and Quaternary unconsolidated deposits are clearly defined and properly registered for they exert the greatest influence in determining the location, extent, and boundary of areas that are susceptible to liquefaction and seismically triggered landsliding. Existing geologic maps, however, vary in quality and accuracy due to differences in purpose of mapping, scale or level of details, inconsistency in nomenclatures, and types of map projection/registration.

Conventional mapping methods of bringing existing geologic maps to the desired quality level or standard will entail a large amount of time and effort and consequently will also drastically slow down the production of the seismic hazard zone maps. The CGS Seismic Hazard Mapping Program (SHMP) strived to find a way to enhance or improve the geologic maps being used in the seismic hazard zoning process that is not only fast and reliable but can be easily incorporated in the zoning process. Thus, an evaluation study was conducted to determine if remote-sensing imagery could prove to be useful in improving or refining the geologic map layers being used in seismic hazard zoning.

The study area for this evaluation is in northern Los Angeles County (Figure 1). Its northeastern part is within the arid Antelope Valley, while the southwestern part is along the northern flank of the San Gabriel Mountains. The study area was chosen for two main reasons: 1) its range of exposed rock materials and geologic features, many of which are amenable to evaluation by remote sensing, and 2) it was part of a zoning project under SHMP.

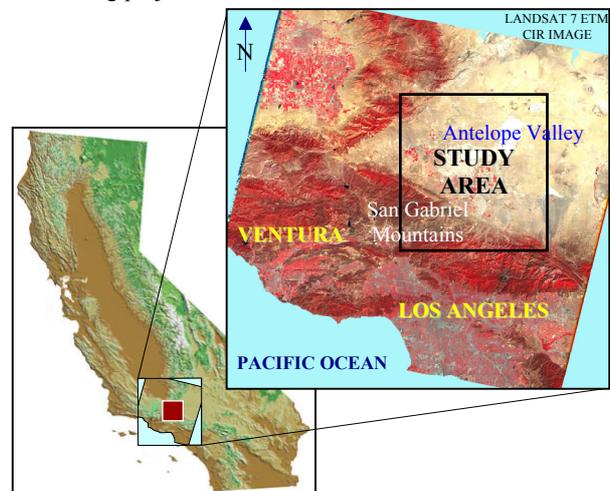


Figure 1. Location Map of Study Area

2. GEOLOGY AND VEGETATION

Geologically, two main environments characterize the area. The San Gabriel Mountains consist largely of Mesozoic and older crystalline rocks (plutonic, schist, gneiss) with local exposures of younger Tertiary sedimentary and lesser volcanic rocks. Antelope Valley is underlain dominantly by unconsolidated alluvium, which surrounds several inliers (buttes) of plutonic rock in the eastern part. The east-southeast trending San Andreas Fault Zone is the dominant structural feature in the area and forms the approximate physical boundary between Antelope Valley and the main San Gabriel Mountains in this region.

Vegetation is present in various compositions and densities, depending largely on elevation, orientation of slope, longitude, and to some extent, underlying lithology. The influence of oceanic moisture is apparent in the western part of the area as indicated by the presence of grasses. As one proceeds eastward, however, vegetation becomes sparser and assumes a “desert” character (creosote, cactus, sagebrush, Joshua trees, etc.) in the fan areas of Antelope Valley. At higher elevations along the front of the San Gabriel Mountains, small trees (juniper, pinyon pine) and shrubs can reach high densities, especially on north-facing slopes. Although casual oblique views across the landscape at ground level suggest that vegetative cover may be substantial, vertical views of these same areas indicate the percentage cover may be much less than expected.

Despite its aridity, the surface of the study area has been substantially changed by cultural activity for many years. Urbanization in the central portion of the area is conspicuous and widespread, and there are large tracts of land to the west and east of this central portion that have been modified through agriculture and subdivision of the land into undeveloped parcels.

3. POTENTIAL APPLICATIONS OF REMOTE SENSING IN THE SHMP

The principles behind remote sensing are rooted in a highly complex application of physics and statistics. The products derived from remote sensing, however, can readily be applied by geologists who need only a basic understanding of these principles. Correspondingly, the main outcome of this study was to determine what potential ways, if any, remote sensing could be applied by geologists in the SHMP to aid their mapping and interpretation of geologic features related to seismic hazards. Another outcome was for all technical staff to start applying remote-sensing imagery to their projects as part of their routine geologic “toolbox.”

Several potential applications of remote-sensing imagery were initially considered in the study ranging from geologic, cartographic, hydrologic, and stereographic aspects. As the study evolved, the evaluation of the use of remote-sensing imagery was concentrated on the following specific geologic applications, or “tasks”:

1. Delineation of contacts between bedrock and unconsolidated Quaternary deposits. These boundaries are important because they separate geologic terrains that SHMP evaluates for *landslide zones* (bedrock) and *liquefaction zones* (unconsolidated deposits).

2. Discrimination of alluvial deposits (fans, modern stream channels, etc.) from one another. This discrimination is important because susceptibility to liquefaction (expressed through *liquefaction zones*) may differ from one type or generation of deposit to another.

3. Discrimination of bedrock units from one another. This discrimination is important because each bedrock unit has inherent shear strengths that are one of the criteria used in *landslide zoning*.

4. Recognition and delineation of landslides. Recognition and mapping of landslides are important for both *landslide zones* and the companion *landslide inventory*.

5. Verification of cartographic registration of digital geologic maps. Acceptable co-registration of previously mapped geology with base maps used in the project is essential for definition of *liquefaction zones* and *landslide zones*.

6. Representation of previously mapped geologic contacts. The more accurate the spatial representation of geologic contacts is, the higher the quality of the interpreted *liquefaction zones* and *landslide zones* derived from them.

4. DATA ACQUIRED AND EVALUATED

To evaluate the use of remote-sensing technology for enhancement of the zoning process by SHMP staff, three categories of data from the study area were required: geologic/soils maps, remote-sensing imagery, and field observations.

4.1 Geologic/Soils Maps

Many sets of published geologic maps (e.g., Ponti and Burke, 1980; Barrows, 1979; Dibblee, 2002a,b; Noble, 1954) and a set of soils maps (Woodruff and others, 1970), which covered all or parts of the study area were obtained to assist in interpretation and evaluation of the imagery. Except for Noble (1954) and the soils maps, all maps were converted to digital form to allow overlay on the imagery.

4.2 Remote-Sensing Imagery

The imagery evaluated in this study included aerial photographs, ASTER, USGS DEM & DOQQ, Intermap RADAR & DEM, Landsat 7 ETM MSS & Panchromatic, and SPOT. Their characteristics are summarized in Table 1.

Remote-Sensing Data	Resolution (meters)	No. of Bands	Date
ASTER (VNIR,SWIR,TIR)	15, 30, 90	14	2001
Intermap DEM	5	1	2001
Intermap RADAR	2.5	1	2001
Landsat 7 ETM MSS	30	6	'99, '00
Landsat 7 ETM PAN	15	1	1999
SPOT	10	1	'98-'00
USGS DEM	10	1	'70-'90s
USGS DOQQ	1	1	1990s

Table 1. Characteristics of Remote-Sensing Data used in the evaluation.

4.3 Field Observations

Fieldwork was undertaken in the study area to observe conditions and characteristics of the ground surface. Done in reconnaissance (the entire study area) and in detail (specific locations in selected areas), the field observations were used to identify and verify the features displayed on the imagery. Terrestrial photographs were taken of typical landscape and features of the area to document topography, rock/soil exposure, vegetative cover, and cultural modifications for later use in the office.

5. EVALUATION PROCEDURES AND METHODOLOGY

5.1 Pre-Evaluation Research of Geology

First, the usefulness and quality of existing geologic/soils maps were reviewed and evaluated. The maps served in general as a means of comparison to help identify areal features shown on the imagery and as a “check” for spectral features on the images where fieldwork was not conducted. Geologic reconnaissance of the entire study area was initially undertaken and then specific areas were selected where utility of the imagery could be best tested.

5.2 Evaluation of Sensor Characteristics

The sensors were evaluated for the following characteristics of their products:

- Availability of images (number of archive scenes, different times of year, etc.)
- Spatial resolution of images
- Spectral resolution of images
- Cost
- General applicability to the study area

5.3 Methods of Imagery Processing

Following the review of the geology and soils data, standard digital processing was applied to the remote-sensing data and imagery to extract information for interpretation of the geology of the study area.

All imagery was processed and observed on ENVI (versions 3.5, 3.6 and 4.2), a standard off-the-shelf commercial software package. Another commercial image-processing package, ILWIS (version 3.1) was used to generate anaglyph stereo and epipolar stereo images, which were viewed with either a mechanical stereoscopic viewer (ScreenScope) or anaglyph glasses directly on a computer monitor. Intergraph MGE and GeoMedia were utilized in vector and raster overlaying. Finally, MapInfo, a desktop GIS, was used occasionally to display images when rapid panning and a range of zoom views were required.

As needed during the preparation of the imagery for evaluation and for use by SHMP staff, “subsetting” (extraction of portions of scenes), conversion of projection to the standard one used by SHMP, and warping were conducted on the remote-sensing data to allow overlaying of vector data on the images for analysis.

The following image processing/algorithms were applied to the package of remote-sensing data described above:

Basic Displays - bands are displayed singly or in combination in either grayscale or color without any mathematical manipulation of the digital data:

- **Single-Band Grayscale** (Figure 2a)
- **True-Color Composite**
- **Color-Infrared Composite**
- **False-Color Composite**
- **Color Mapping** (Figure 2b)

Transformations – image processing operations that “transform” the data by mathematical algorithms into other forms or space. The main purpose of transformation is to improve visual presentation of the data so that the image is more easily interpreted and thus more information can be extracted:

- **Image Sharpening** (Figure 3a)
- **Band Ratios**
- **Principal Components Analysis (PCA)** (Figure 3b)
- **Minimum Noise Fraction Rotation (MNF)**
- **Decorrelation Stretch**
- **Color Transform**
- **Saturation Stretch**
- **Synthetic Color Image**
- **Normalized Difference Vegetation Index**
- **Tasseled Cap**

Topographic Modelling – potentially improves the interpretation of images by adding 3-dimensional effect to them:

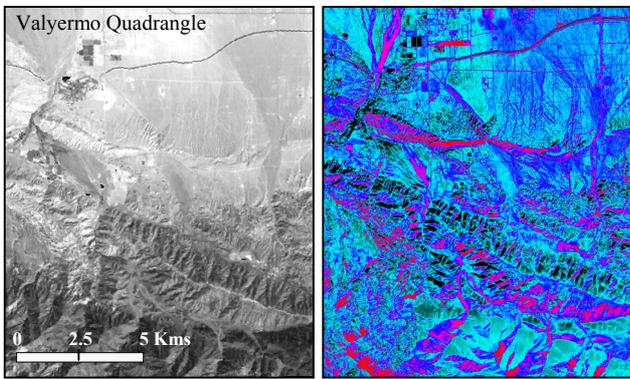
- **Shaded Relief**
- **3-D Surface View**
- **Hill Shade** (Figure 4a)
- **Anaglyph** (Figure 4b)
- **Epipolar Stereo**

Classification – the process of grouping pixels of an image into categories or classes, according to their similarity. This process works well for pixels composed of discrete surface materials, but not as well for pixels composed of a wide mixture of materials, which causes noise and ambiguity in the resulting image:

- **ISODATA** (Figure 5a)
- **K-means** (Figure 5b)

Combination Images – images prepared by merging bands of data from more than one sensor to produce a single image that displays useful properties from each of the sensors. Besides Image Sharpening and Hill Shade, which are special cases of this processing, other combination images prepared included the following:

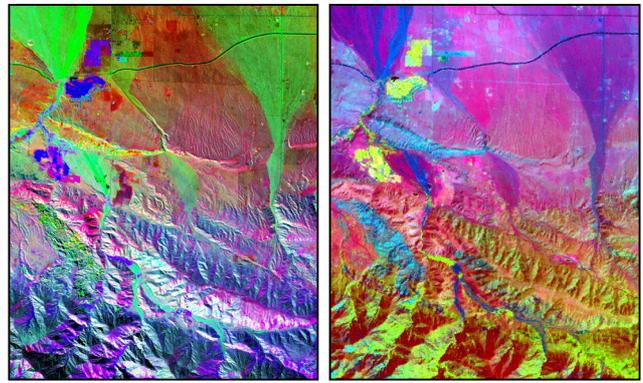
- **Band Ratios of ASTER VNIR and SWIR**
- **Landsat TM 432 Fused with Intermap Radar**
- **ASTER TIR Fused with Intermap Radar**



a) Single-Band Grayscale
Landsat 7 ETM, B5

b) Color Mapping
SPOT Pan, RB

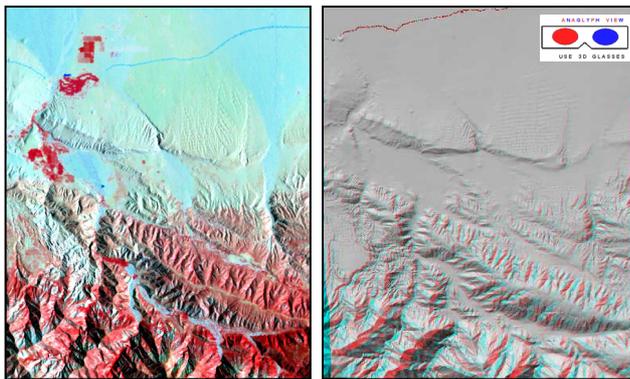
Figure 2. Examples of Basic Displays



a) Image Sharpening
Landsat 7 ETM + SAR

b) Principal Components
Landsat 7 ETM

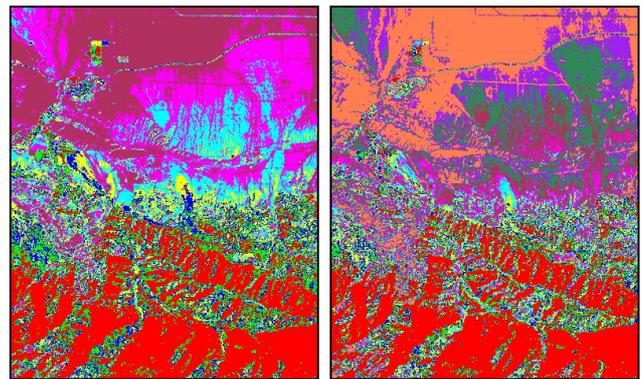
Figure 3. Examples of Transformations



a) Hill Shade
Intermap DEM + Color IR

b) Stereo Anaglyph
USGS DEM

Figure 4. Examples of Topographic Modelling



a) ISODATA
Landsat 7 ETM

b) K-means
10 classes

Figure 5. Examples of Classification

5.4 Methods of Evaluating the Imagery

After image processing was completed to produce derivative images, they were analyzed and evaluated for geologic features using one or more of the techniques described below:

1. Viewed the images on-screen to discern patterns, features and boundaries. This process is termed “scientific visualization,” which is defined as visually exploring data and information in such a way as to gain understanding and insight into the data (Jensen, 1996).
2. Compared these results to the published geologic and soils maps either visually or by overlaying vector lines of the geology on top of the images.
3. Plotted selected images and then checked/verified the actual surface materials and features in the field.
4. Visually compared two or more sets of alternative imagery with the image being evaluated to aid interpretation of features observed. For example, images generated from ASTER were compared to the features on the corresponding DOQQ and Landsat 7 ETM images.

6. RESULTS OF EVALUATION

In general, analysis revealed discrepancies as well as reasonable agreement between specific features portrayed on

the geologic maps (e.g., contacts) and corresponding features on the remote-sensing images. Highlighting the discrepancies can help the project geologists select sites to investigate in the field or re-evaluate concerning final geologic boundaries for zoning.

6.1 Geologic/Soils Maps

The most important data derived from the geologic maps were the contacts between bedrock and unconsolidated Quaternary deposits and the subdivision of bedrock units into lithologic type. The soils maps were applicable mainly in the low-lying alluvial areas of Antelope Valley and provided local alternative interpretations of the boundaries between bedrock and unconsolidated Quaternary deposits.

6.2 Sensor Characteristics

The utility of sensors improves as: a) cost for imagery goes down, b) the number of available archive scenes gets larger, and c) refinement of spatial and spectral resolution increases. Considering these factors, no one sensor that was evaluated possessed all of the most desirable characteristics. Nonetheless, all sensors offered something useful for SHMP applications. ASTER was determined to be the best single sensor overall for its versatility in the categories evaluated.

Geologic Mapping/Hazard Zoning Applications	Image Processing/Algorithm																					
	Basic Displays				Transformations								Topographic Modelling				Class					
	Single-Band Grayscale	True Color Composite	Color IR Composite	False Color Composite	Color Mapping	Image Sharpening	Band Ratios	Principal Components	Min. Noise Fraction	Decorrelation Stretch	Color Transform	Saturation Stretch	Synthetic Color	NDVI	Tasseled Cap	Shaded Relief	3D Surface View	Hill Shade	Stereo Anaglyph	Epipolar Stereo	Isodata	K-means
1. Delineation of contact between bedrock and unconsolidated Quaternary deposits.	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
2. Discrimination of alluvial deposits (fans, modern stream channels) from one another.	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
3. Discrimination of bedrock units from one another.	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
4. Recognition and delineation of landslides	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
5. Verification of cartographic registration of digital geologic maps.	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High
6. Representation of previously mapped geologic contacts.	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High	High

Table 2. Summary of evaluation of different remote-sensing imagery for six specific SHMP geologic applications in the northern Los Angeles County study area.

6.3 Remote-Sensing Imagery

The results of the evaluation of the usefulness of the different algorithms for the six specific geologic applications pertinent to SHMP are summarized in Table 2.

7. CONCLUSIONS

The following conclusions pertain to which evaluated imagery and algorithms worked best for the six specific geologic applications in SHMP mapping and zoning for this study area:

Application 1 - Remote-sensing imagery ranged from highly useful in some parts of the study area to minimally useful in other parts. Its best use was for juxtaposed alluvial and bedrock areas that have both different spectral signals and conspicuously different topographic signatures. Shaded relief and principal components-based algorithms (Figure 6b, i, & j) were most applicable in these areas. Imagery was least useful in the vegetation-covered contact zone along the range-front in the southwestern part of the study area.

Application 2 – Enhanced versions of principal components algorithms (MNF, PCA, Decorrelation Stretch of ASTER) (Figure 6b, d, f & h) were particularly effective in recognizing individual alluvial fans. Older fans were also easily discernable because of their surface textures related to degree of dissection, which can be well-displayed on shaded

relief and hill shade imagery. Within individual fans, active channels were spectrally distinct.

Application 3 – Within the bedrock terrain of the study area, successful discrimination of bedrock units from one another by remote-sensing imagery ranged from high to low. The most important influence on success was the percentage of vegetative cover. Special image processing may help discriminate lithology in areas obscured by vegetation, but unless there is a direct unique correlation between the vegetation community and the underlying rock, or there is a preference of vegetation to concentrate along structural features of the rock, vegetation cover generally hinders discrimination. Successful discrimination was much more common in the eastern part of the study area where vegetation is generally sparse. Of the imagery evaluated, those in the principal-components family (PCA, Decorrelation Stretch) applied to ASTER (Figure 6a, c & g) and Landsat 7 were the most helpful in discrimination.

Application 4 – For this study area, remote-sensing imagery in general was not found to be especially useful for recognition and mapping landslides. One problem with evaluating landslides here is that the climate is semi-arid to arid, and most landslides are very old and thus not conspicuous, especially in the foliated metamorphic terrane. The topographic-modelling group, particularly shaded relief generated from USGS and Intermap DEMs, proved to be the most useful in this application.

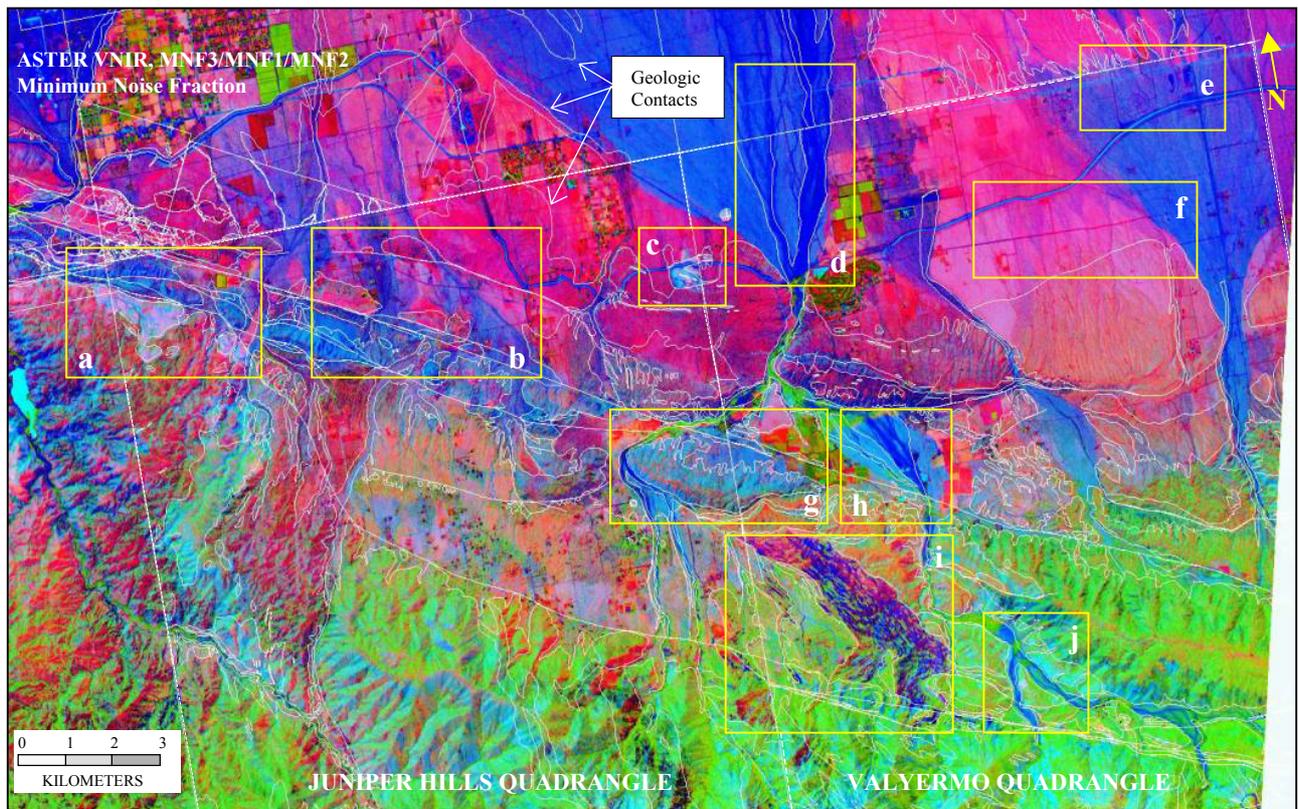


Figure 6. ASTER image of portions of Juniper Hills and Valyermo quadrangles with overlay of geologic contacts (white) of Dibblee (2002a, 2002b) and Ponti and Burke (1980). Examples of geologic information include: **a**) discrimination of Tertiary volcanic rocks (lavender/blue) from granitic rock (pink), **b**) younger alluvium (blue) among older alluvium and granitic bedrock (pink), **c**) gabbro (blue) within quartz monzonite (pink), **d**) delineation of active channels (dark blue) in young alluvial fans, **e**) refinement of previously mapped alluvial contacts (pink) adjacent to structural boundary, **f**) discrimination of older alluvial units (shades of pink), **g**) more-mafic plutonic rock (blue), **h**) discrimination of younger alluvial units (shades of blue), **i**) discrimination of Tertiary sandstone (purple), **j**) contact between bedrock (green) and alluvium (dark blue).

Application 5 - Certain georeferenced and orthorectified remote-sensing imagery was excellent for checking the accuracy of cartographic georegistration of digital vector layers of the geologic maps with SHMP digital base maps. Shaded-relief imagery generated from the USGS and Intermap DEMs was among the best for this application wherein the most effective means of analysis of georegistration was by visual observation of the digitized contacts between recent alluvial deposits and bedrock.

Application 6 - All published and unpublished geologic maps have inherent errors and levels of detail in how they portray contacts between geologic units. Remote-sensing imagery ranged widely from excellent to poor in its ability to offer visible evidence of the actual contacts. Images generated from the principal-components family of algorithms (Figure 6c & e) were especially useful for this purpose. In some cases shaded relief was also useful in checking where contacts are defined by abrupt topographic changes.

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