AUTOMATING INTERPRETATION OF GEOLOGICAL STRUCTURES FROM LANDSAT TM MULTI-SPECTRAL IMAGES AND DEMs

A. C. Demirkesen[a,*], N. W. J. Hazelton[b] and D. M. Sauder[c]

[a]Dept. of Geodesy and Photogrammetry Eng., Niğde University, 51100 Niğde, TURKEY - ademirkesen@yahoo.com
[b]Dept. of Civil and Env. Eng. and Geodetic Science, The Ohio State University, Columbus, OH, 43210, USA - hazelton.5@osu.edu
[c]Dept. of Civil and Env. Eng. and Geodetic Science, The Ohio State University, Columbus, OH, 43210, USA - sauder.21@osu.edu

KEY WORDS: Interpretation, Extraction, Classification, Imagery, Raster, Geology, Geomorphology

ABSTRACT:

In this study using the Idrisi software system, a methodology for jointly analyzing and interpreting multi-spectral images and DEMs for extracting structural-geology features is given. In analyzing and interpreting multi-spectral images for geological features, certain criteria are employed to acquire information about the geological structures of the land, such as topographic, geomorphologic, and tectonic structures. The main criteria are color and color tones, topography, stream drainage patterns, and vegetation anomalies. In this study, Landsat TM multi-spectral images and a DEM of the Sierra Nevada region, California, USA, were experimentally used for geological interpretation. The results are presented and discussed in this paper.

1. INTRODUCTION

As a means of ensuring efficiency in interpretation of landforms and structures on the Earth from multi-spectral images and DEMs, and to produce multi-scaled geological maps in a digital environment with minimum expense, automatic interpretation of multi-spectral images and DEMs has become widely used as a remote sensing application. One field in Earth surface interpretation from imagery is photo-geology. Photo-geology extracts geological structures to produce geological maps from aerial photos and/or satellite images.

In this study, a methodology that simultaneously analyzes both Landsat TM multi-spectral images and DEMs, and extracts geological features for geological map production, is given. In the methodology, when interpreting multi-spectral images and DEMs, certain criteria are employed to acquire information about the geological structure of the land. The criteria are color and color tones, topography, and geomorphology, stream drainage patterns, and vegetation anomalies.

For this study, Landsat TM multi-spectral images and the DEM of the Sierra Nevada region, California, USA, were experimentally used for geological interpretation. For image processing and analysis, the Idrisi software package, a remote sensing and geographic information system, was employed. The results are presented and discussed in this paper.

Considering the four criteria, the study has essentially undertaken a structural interpretation (determination of geomorphology, lineations and line features, faults and folds, vegetation anomalies, stream drainage patterns) rather than a petrographic or lithologic interpretation (determination of rock types and boundaries of geological formations). The four criteria have been experimentally employed for automating geological interpretation and geological information extraction from Landsat TM multi-spectral images and DEMs using Idrisi.

2. GEOLOGICAL INTERPRETATION OF IMAGERY AND DEMs

2.1 Color and color tones

Color and color tones are the brightness levels in digital images. Reflection of color tones of different materials on the Earth helps distinguish different materials and their boundaries. For instance, water is distinguished from soil since the water has a different tone than the soil (Lillesand and Kiefer, 1994; Konecny, 2002; Prost, 1994). In this study, the true color composite image with RGB=321 (where R=Red, G=Green, and B=Blue Bands, and 321 is Band 3, Band 2, and Band 1 of Landsat TM multi-spectral image), two false color composite images, RGB=432, and RGB=743 (see Figures 1, 2, and 3, respectively) were used to interpret geological structures and distinguish them from other land surface materials. In the RGB=743 false color composite image, dark area is water (lake and river), green area is vegetation (trees), and red area is ground (bare rocks).

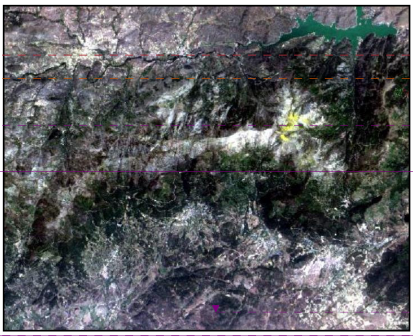

Figure 1. True color composite image RGB=321

Color and color tones also show shapes and sizes of features. Shape is the geometric outline of an object. This outline gives information about the nature and geometry of the object. Size is the magnitude of an object or a single dimension of the object (e.g., the length of a river). Once we look at an image, our eye-brain cognitive system automatically assigns a scale to the

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object in the image. We simply recognize objects, such as a house, tree, or road, then knowing their size, we can figure out the dimensions of other objects in the same image and recognize the extent or coverage of the entire image.

Color and color tones constitute textures of features. Texture describes the structure of the variation in brightness within an object as well. Vegetation and water in certain spectral bands may have the same mean brightness, but they may have different textures. Therefore, they can be differentiated using the texture knowledge of vegetation and water.

Finally, color and color tones also show shadows. Shadows can be used to figure out topography and geomorphology, i.e., heights of features and mountain ridges and directions of plate tilts. For instance, the image in Figure 5 that shows topography and geomorphology was created by shading the DEM data in Figure 4 (Idrisi, 1997).

A set of rules that allow analysis of the terrain based on color and color tone, among other factors, was developed (Demirkesen, 2001) and used in this study. Such rules provide the foundation for an automated system to aid image analysis and scene understanding.

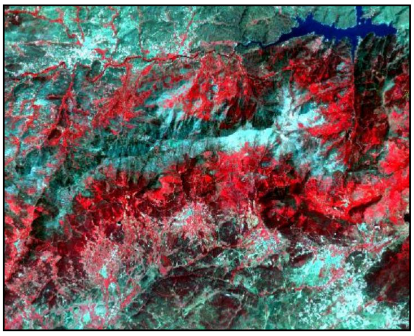

Figure 2. False color compsite image RGB=432

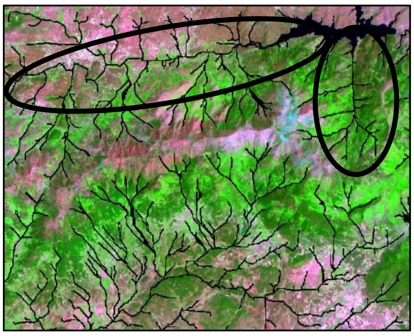

Figure 3. False color compsite image RGB=743 with overlaid stream drainage patterns

2.2 Stream drainage patterns

Geomorphologists dealing with remote sensing applications have studied stream drainage patterns and their relationships to terrain conditions. Many have deduced different rock properties and structures using topographic relief interpretation from the imagery. They have illustrated and quantified relationships among selected rock properties, topographic relief, and stream drainage patterns (Drury, 2001; Konecny, 2002; Lillesand and Kiefer, 1994; Pandey, 1987; Prost, 1994; Ray, 1960).

Stream drainage density in eroding rock landscapes can be explained by a function of rock resistance to weathering, topography and climate. Rock resistance to both chemical and mechanical weathering is an important factor in explaining drainage patterns. In terms of topography, higher relief creates a finer-textured drainage as in our study image. But the relationship with climate is more complicated. It is the amount of protective vegetation cover, which can be correlated to temperature and precipitation, that significantly controls erosion and drainage density. Thus softer rocks, such as shale areas, have higher drainage densities in drier climates than wetter climates. The protection of the rock and soil surface by vegetation compensates for the increase in precipitation.

Stream drainage density usually indicates the porosity and permeability of the underlying materials. Materials with good permeability generally have a medium to coarse drainage density. Such materials include sandstones, terrace gravels, limestones, volcanic ashes, and sand dunes.

Stream drainage density also shows that fine-grained or impermeable materials have little moisture on the surface. This moisture does not infiltrate and must run off on the surface. This causes a dense integrated drainage network. Shales, fine-grained volcanic ashes, mudflats, and igneous and metamorphic rocks that weather to clays (e,g., gabbros, serpentinities, schists, slate and highly altered granitic rocks) usually have fine-textured drainage patterns.

Stream drainage patterns can reveal larger-scale coarse structure of underlying rocks, e.g., stream drainage patterns with numerous straight parallel or sub-parallel segments can indicate extensive jointing on dipping bedded or foliated rocks. Consistent angular relationships between stream elements indicate fractures. Co-centric drainage shows doming of layered sequence of rock related to intrusion or folding. Radial drainage shows doming, volcanic activity, or small resistant cylindrical intrusions in less resistant rocks. Well-developed dendritic drainage patterns (as in our study image) without well-developed parallel elements suggest a uniform stratum without abundant discontinuities. This can consist of sedimentary, igneous, or metamorphic rocks, or sheets of relatively uniform glacial or alluvial materials. Distributed channel patterns indicate alluvial fans, pediments, or deltas, and they are usually associated with an abrupt decrease in stream velocity. Extensive drainage channels indicate strong foliation, dipping sequences of resistant and nonresistant rocks, or strong unidirectional fracturing.

The shapes of the main channels in the stream drainage area also provide clues about the geological structures. For instance, braided channels indicate easily erodible coarse-grained materials, while meandering channels indicate medium to fine-grained materials. Relatively narrow and straight channels indicate resistant materials, but abrupt changes in channels indicate changes in geological structures. Extreme changes in channel types indicate changes in the materials that make up the bank. The main channel in the drainage area having discontinuities indicates cracks (breaks and fractures) and/or faults, as well as unconformities.

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Stream drainage patterns can be classified into 11 main categories as follows (Demirkesen, 2001).

1. **Dendritic** is the most common stream drainage pattern. It looks like a tree with branching channels in many directions (e.g., Sabina River in Texas and the Mississippi River in Mississippi). This pattern shows up on homogeneous, uniform soil and rock materials mostly in sedimentary rocks. Figure 6 shows a homogeneous fine textured dendritic stream drainage pattern.
2. **Trellis** is a modification of the dendritic pattern, with parallel tributaries and short parallel gullies, which occur at nearly right angles (e.g., Hiwassee River in Tennessee). This pattern shows up on a folded bedrock structure, dissected coastal plains, and folded and faulted sedimentary rocks, in which the main parallel channels follow the strike of the beds.
3. **Rectangular pattern** is a variation of the trellis pattern. The tributaries join the main stream at almost right angles (e.g., Batoka Gorge of Zambezi River in Zambia). This pattern shows up on the outcropping edges of folded sedimentary rocks (weak or resistant) with long and roughly parallel belts.
4. **Radial** is also called a centrifugal pattern. Channels radiate out, like the spokes of a wheel, from a topographically high area. They show up on volcanoes, isolated hills, and dome-like landforms.
5. **Annular** is a circular pattern that occurs most frequently as a result of erosion on structural domes. This pattern is a curved trellis pattern and nearly concentric. This kind of pattern develops on topographic forms generally similar to radial patterns. However, in this case, the bedrock joints or bedrock fracturing control the parallel tributaries. Granite or bedrock sedimentary domes may develop this type of pattern.
6. **Centripetal** pattern is the opposite of the radial stream pattern. Flows are directed toward a central point. They occur in areas of limestone sinkholes, glacial kettle holes, volcanic centers, outwash terraces, alluvial beach ridges, sand dunes and other depressions.
7. **Pinnate** looks like a feather, and is a modification of the dendritic pattern, but its secondary tributaries are evenly and closely spaced and parallel. It indicates a high silt content of soil, and bedrock features control the tributaries.
8. **Parallel** tributaries join the mainstream at roughly the same angle. This occurs on homogeneous, gentle, uniformly sloping sedimentary surfaces whose main collector streams may indicate a fault or fracture. This is also found on tilted coastal or lake plains.
9. **Thermokarst** develops in poorly drained, fine-grained sediments and in organic materials in regions of thick soil and especially in permafrost. Freezing causes many cracks to develop polygonal shapes and depressions. Streams crossing this area may connect these rounded depressions and create multi-basin stream patterns. Note that rivers can also disappear by running underground in karst area and then reappear as surface flow. This can be observed as a discontinuity of the river on the terrain. However, rivers are continuous, even if part of the river isn't visible.
10. **Deranged** is a disordered pattern of randomly directed streams, ponds, and wetland areas, and an instance of a multi-basin drainage pattern. It occurs on glacial tilted areas and flood plains.
11. **Artificial** is artificially constructed waterways, as for irrigation; a pattern characterized by straight lines. It carries water into agricultural fields.

Rules for classifying the nature of the stream pattern were developed (Demirkesen, 2001) and applied in this study.

2.3 Topography and geomorphology

DEMs are frequently employed as a digital representation of a topographic surface. They are usually in the form of a regular lattice of spot heights. DEMs may be derived by interpolation of a surface produced from irregularly spaced points, or derived directly using digital photogrammetry. DEMs are usually stored in a raster-like scheme (Demirkesen, 2001).

Figures 4 and 5 show the topographic roughness and geomorphological structure of the study area. The DEM is employed for structural-geological and tectonic interpretations, such as locating drainage patterns, faults, cracks, valleys, ridges, plate positions, plate tilts, slope and aspect, folded structures (anticline and syncline), angled discordance, lineaments, and the boundaries of geological formations.

Geomorphologists have used both DEMs and images together for tectonic and geomorphological interpretation, such as finding the tilt direction of rock layers. For example, they have used the V-rule to find tilts of plates. Intersections between tilted plates and surfaces of valleys are V-shaped. The corner of the V indicates the tilt direction of the rock layer. In other words, by looking at the boundaries of plates in valleys, the direction of tilt can be observed and determined. In general, a sharp tip of the V in rock layers shows slope direction. This rule is very useful for tectonic interpretation, such as for recognizing faults and folds, from the imagery.

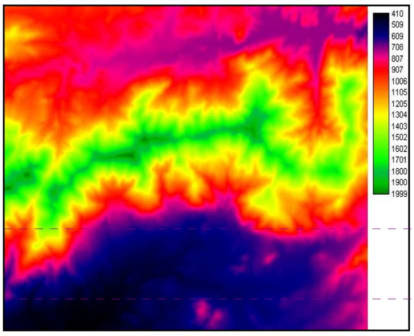

Figure 4. Digital elevation model (DEM)

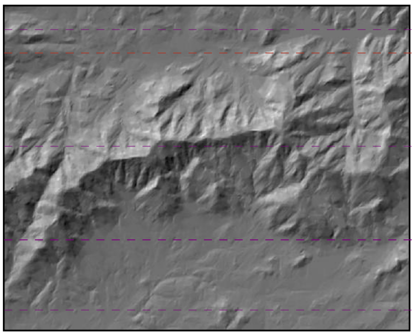

Figure 5. Topography and geomorphology

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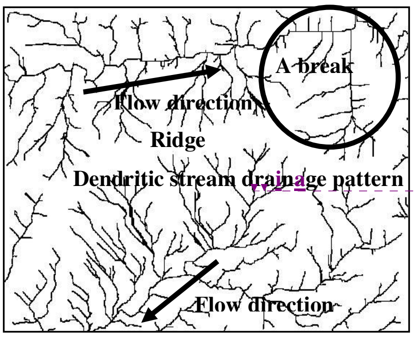

Figure 6. Stream drainage pattern of the study area

2.4 Vegetation anomalies

Figure 7 shows extracted vegetation density using the Normalized Vegetation Difference Index (NDVI) method in Idrisi (Idrisi, 1997).

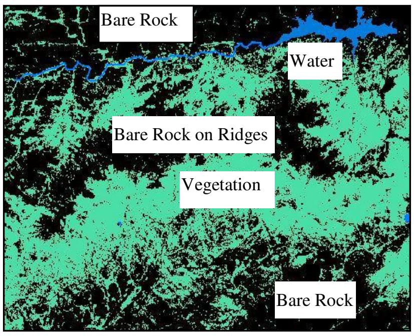

Figure 7. Vegetation anomalies with overlaid water bodies

Vegetation makes geological interpretation difficult since it camouflages the land. Nevertheless, it gives us some important information about geological structures. For instance, vegetation types and density develop depending on geological structures. Thus, vegetation patterns are used as clues. Vegetation cannot grow in basalt, salt, or marble areas. This information is used for petrographic interpretation (Drury 2001; Pandey, 1987; Prost, 1994; Ray, 1960).

Vegetation anomalies can indicate fault lines, drainage patterns, and boundaries of foliated rock formations. For instance, the clustering of vegetation along valleys, the appearance of vegetation around water bodies, and sudden changes in the area's geomorphology give us important information about the geological structures of the land surface, particularly about faults (Drury, 2001; Pandey, 1987; Prost, 1994; Ray, 1960).

3. ANALYSIS OF UNDERLYING ROCKS IN IMAGERY

Topography and geomorphology are controlled by geological structures and by erosional characteristics of the underlying rocks. Rocks can be recognized by the textural expressions of the surface in imagery.

3.1 Carbonate rocks

In humid environments, the dissolving and collapsing of carbonate rocks produce karst topography, which is readily recognized by a distinctive pitted surface. Faulting and stream erosion may obscure the expression of karst topography.

3.2 Clastic sedimentary rocks

The study area is most probably formed from clastic sedimentary rocks, primarily sandstones and shales. This is recognized from stratification that forms asymmetric ridges, called cuestas and hogbacks, where the rocks are dipping. Flat-lying clastic rocks form mesas, terraces, and associated erosional scarps. The absence of karst topography generally distinguishes clastic terrain from carbonate terrain in humid regions.

3.3 Volcanic rocks

Volcanic rocks form irregular flows associated with cinder cones or eroded volcanic necks. Because of erosion and deformation, older volcanic terrains lack these distinctive features. These kinds of volcanic rocks cannot be seen in our study area since our study area has a regular homogeneous dendritic stream drainage pattern that indicates sedimentary rocks.

3.4 Alluvial and coastal rocks

This category shows low relief characteristics, a uniform bright signature of heavily vegetated floodplains, and dark signatures of calm water in meandering streams. However, our study area reveals slight lineaments and dendritic drainage anomalies of a sedimentary geological structure.

3.5 Melange rocks

Melange refers to rocks formed in subduction zones as a mixture of clastic sediments and oceanic crustal and mantle rocks. Rock fragments of a wide range of sizes, up to kilometers in length, are enclosed in a matrix of clay. Erosion of these rocks produces an irregular, rounded terrain with unsystematic drainage patterns. Stratification and individual rock fragments cannot be seen in our image because of the scale.

3.6 Metamorphic rocks

When sedimentary rocks have been metamorphosed to slate, quartzite and schist, metamorphic rocks occur. The original stratification is not recognizable in our study image. Strongly dissected metamorphic terrain has high relief and angular ridges that distinguish it from the low relief and rounded appearance of melange terrain. Foliation trends are not discernible in our study image. Also, crystallization that indicates metomorphizm cannot be seen in our image.

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4. ANALYSIS OF GEOLOGICAL STRUCTURES IN IMAGERY

In order to understand earthquakes, one must know about faults. Knowing how major mountains sequences and the continents have occurred is closely associated with the comprehension of faulting and folding. Understanding plate-tectonic theory requires a knowledge of structural geology. In areas of active tectonics, the location of geological structures is important in the selection of suitable sites for houses, schools, hospitals, dams, bridges, factories, and nuclear power stations. Additionally, understanding structural geology is useful for solving the problem of finding natural resources. For instance, petroleum sites can be predicted based on the presence of certain geological structures.

Structural geological interpretation of faulted landforms is of importance to land users. Active faults pose natural hazards, and dormant faults profoundly affect excavation, tunneling, and the geometry of mineral deposits and petroleum accumulations. Faults are fractures that displace the rocks on either side of the fault.

4.1 Strike and dip

The strike is the azimuth of the horizontal line formed by the intersection of an inclined plane, such as a bedding plane, with a horizontal plane. The direction of dip is the azimuth in which the angle of dip is measured, usually perpendicular to the strike. The angle of dip is a vertical angle measured downward from the horizontal plane to an inclined plane.

Strike and dip information can be interpreted in carbonate and clastic terrains and in some volcanic terrains where flow surfaces are well expressed. The image signature of dipping layers depends upon the relationships among the dip direction, look direction and look angle. Dip slopes have bright signatures and anti-dip scarps in shadows have dark signatures.

4.2 Faults

A fault is a fracture in bedrock along which movement has taken place. Movements along faults cause earthquakes. For instance, the continuous movement of the Earth's crustal plates can squeeze, stretch, or break rock strata, deforming them and producing faults and folds. Faults tend to occur in hard, rigid rocks, which are more likely to break rather than bend. Faults can be classified into the three main categories. They are dip-slip faults, strike-slip faults, and oblique-slip faults. McGeary (1996) and Strahler and Strahler (1994) provide a detailed discussion of these issues, and the reader is referred there for more information.

Thrust or reverse faults form in compressive environments where the maximum principal compressive stress is horizontal and minimum compressive stress is vertical. These faults are difficult to interpret from Landsat TM and even from radar remote sensing images. This is because the planes of most thrust faults are parallel or nearly parallel to the bedding planes of associated strata. Most thrust faults do not cause the discordant geometric relationships that are associated with many normal and strike-slip faults. In addition, thrust faults are recognized in the field by anomalous rock relationships, such as older beds over younger beds, repetition of belts, and omission of beds. These relationships are difficult to recognize on images without the aid of field data.

A strike-slip fault is a fault in which movement is parallel to the strike of the fault surface. Strike-slip faults are also compressive faults (both maximum and minimum compressive stresses are horizontal), but instead of rocks overriding each other, the fault displaces rocks horizontally. Fault planes are vertical or dip very steeply, and the traces of strike-slip faults tend to be straight and extend for long distances. Rocks on both sides of the fault tend to be strongly deformed in the vicinity of the fault, and structures on either side of the fault appear to be dragged into or along the fault. Movement along these faults produces many of the most devastating earthquakes, as in Turkey in 1999.

4.3 Folds

In folded structures, a fold is a bend in a rock layer caused by compression. Folds occur in elastic rocks, which tend to bend rather than break. Two main types of folds are anticlines (up folds) and synclines (down folds). Folds can change in size from a few millimeters long to folded mountain ranges hundreds of kilometers long. Folds may be recognized by attitudes of beds, outcrop patterns, and topographic expression. McGeary (1996) and Strahler and Strahler (1994) provide an extensive discussion of this topic. Folds cannot be seen in our study image.

5. RESULTS AND DISCUSSION

Remote sensing analysis has often taken a somewhat haphazard approach. The experienced analyst tries a range of tools and looks to see what works best, i.e., which result looks 'right.' 'Right' is often based on long experience and considerable expertise, but tends to be based on the individual analyst's skills. This is a consequence of attempting to deduce the nature of a complex mix of variables in reality from a small set of reflectance values in the image.

Because of the need for the analyst's expertise in rapid recognition of complex image patterns, no fully automated system is likely to be effective or correct. One objective of this study has been to test some of the limits of the analytical process using a rules-based approach. If we can present a number of analytical scenarios to the analyst for consideration, then proceed to further analysis based on choices made by the analyst, we can make the process more effective and efficient.

This method of automation keeps the people in the analysis loop, but tries to shift much of the low-level work to the computer, while leaving the high-level recognition work to the human expert. This system is one of shared cognitive responsibility (Turk, 1990, 1992).

Implementing the rules base in Idrisi was fairly straightforward, as the software allows integration of imagery and cell-based GIS data, such as DEMs. Idrisi has a macro capability, which allows the development of routines that will run a complex analysis based on rules and other instruction. It would be possible to implement this methodology in a number of other packages such as the GRASS GIS.

The results of this analysis show that the Sierra Nevada area in the study image has an homogeneous, fine texture-scaled dendritic stream drainage pattern. This means the area most likely has clastic sedimentary rocks. The image of the area also does not indicate a significant fault line according to the stream drainage patterns, such as trellis and rectangular stream drainage patterns. However, looking at the upper right corner of the image, a break line in the stream drainage pattern shows

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there is some possibility of local fault line (see Figure 6) in the study area.

Looking at vegetation, dense vegetation can be seen and the edges of vegetation show formation boundaries. Vegetation anomalies also do not show the sudden linear change that indicates a fault line. There is a river channel integrated with vegetation showing a geological formation boundary.

In this study, we have used Landsat TM multi-spectral imagery and a DEM having a 30m horizontal resolution. This is satisfactory for working with 1:100 000 - 1:250 000 mapping. But a 30m resolution image is not effective for extracting some geological structural features, such as rivers, drainage patterns and faults, given the random errors involved and error propagation during the interpretation process. We recommend the use of multi-spectral images having a resolution of at least 5 to 10m horizontally, depending on the map scale and the purpose of the interpretation. This will be adequate for 1:5 000 - 1: 25 000 mapping. Today, 1 or 5m resolution multi-spectral imagery is provided by many commercial imaging companies. In these high-resolution images, automated interpretation will be more accurate and reliable because of the finer geometric and radiometric detail.

After the results of interpretation and analysis are obtained in a map form, ground truth verification should be done using ground control points and checked in the field.

6. CONCLUSION

The purpose of this study was to use a methodology that as much as possible automatically interpreted and analyzed both a multi-spectral image and a DEM of the same area for obtaining geological information. In the study, we employed automated extraction of the stream drainage patterns from the DEM, and constructed geomorphology by shading the DEM. We then created the best color composite images and extracted vegetation anomalies by the NDVI method from multi-spectral images for automated interpretation of geological structures.

Next, the four criteria were used for photo-geological interpretation: color, color tones, and vegetation anomalies were applied to the color composite images; stream drainage patterns, topography, and morphology have been applied to the DEM. A set of rules allowed the computer to undertake a large amount of the basic computational work unaided.

The methodology supports shared-cognitive responsibility for decision-making in geological interpretation. It reduces uncertainties in decision making in recognizing geological structures and geomorphological features in multi-spectral images and DEMs. The methodology enables remote sensing facilities to locate structural geological features and undertake interpretation in an easier, more accurate and straightforward way. It also allows existing expertise to be used as efficiently as possible.

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1. INTRODUCTION

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2. GEOLOGIC INTERPRETATION OF IMAGERY AND DEM

2.1 Color and color tones

Color and color tones are the brightness levels in digital images. Reflection of color tones of different materials on the earth helps us distinguish the materials and their boundaries. For instance, water is distinguished from soil since the water has different tone than the soil (Lillesand and Kiefer, 1994; Konecny, 2002). In this study, the true color composite image with RGB=321 (where R=Red, G=Green, and B=Blue Bands, and 321 is Band 3, Band 2, and Band 1 of Landsat TM multi-spectral image), and a false color composite image RGB=432, and another false color composite image RGB=743 (see Figures 1, 2, and 3, respectively) were used to visually interpret geologic structures and distinguish them from other land surface materials. These color composite images are the examples showing information acquisition about the earth materials using color and color tones. In the RGB=743 false color composite image, dark area is water (lake and river), green area is vegetation (trees), and red area is ground (bare rocks).

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For example, iron cemented sandstones form the coarse drainage patterns influenced little by topography and climate. Another example, shale areas (e.g., soil as clay and silt) have a fine-textured drainage that is a reflection of both topography and climate.

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Drainage is slightly denser in so heavy rainy areas due to the increase in runoff without a corresponding increase in vegetation cover. (Drury, 2001; Lillesand and Kiefer, 1994; Pandey, 1987; Ray, 1960).

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Shadows show the reflection of shades due to the sun lights.

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Any precipitation that falls on these materials either infiltrates or is carried off in a sparse network of surface drainage. The end members of these materials are extensive dune sands and karstic limestone plains, which may have no integrated surface drainage (Drury, 2001; Lillesand and Kiefer, 1994; Pandey, 1987; Ray, 1960).

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(Drury, 2001; Lillesand and Kiefer, 1994; Pandey, 1987; Ray, 1960).

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(Drury, 2001; Lillesand and Kiefer, 1994; Pandey, 1987; Ray, 1960).

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(Drury, 2001; Lillesand and Kiefer, 1994; Pandey, 1987; Ray, 1960).

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So, DEMs denote the digital elevations of a surface by regular grid cells or by a random set of elevation points connected by a triangulation. DEMs consist of elevation data which are stored like a digital image where gray values represent elevations. In most cases, DEMs are irregular grid cells and derived by photogrammetric mapping from aerial photographs and satellite images

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This pattern forms rectangular shapes that are controlled by bedrock cracks.

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, such as a dome or a volcanic cone

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Therefore, geomorphologists have used both DEMs and images together for tectonic and geomorphologic interpretation finding tilt direction of rock layers. For example, they have used the V-rule to find tilts of plates. Intersections between tilted plates and surfaces of valleys are V-shaped. The corner of V indicates the tilt direction of the rock layer. In other words, by looking at boundaries of plates in valleys, direction of tilt can be observed and determined. Thus, in general, sharp tip of V in rock layers shows slope direction. This rule is very useful for tectonic interpretation, such as for recognizing faults and folds from the imagery.

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(McGeary, 1996; Strahler and Strahler, 1994).

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(McGeary, 1996; Strahler and Strahler, 1994).

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So, a fault is a fracture in a rock along which there is movement of one side relative to the other. The movement can be vertical, horizontal, or oblique.

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The smallest faults occur in single mineral crystals and are microscopically small, whereas the largest – the Great Rift Valley in Africa – is more than a 9000 kilometer length.

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Dip-slip faults are normal and reverse faults causing graben and horst. Strike-slip faults are left and right lateral faults. Oblique-slip fault is a fault with both strike-slip and dip-slip components (

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Normal faults displace rocks vertically. These faults form in extensional environments and have steep dips, usually between 45^0 and 75^0. Like all faults, normal faults are shear failures; they indicate that the maximum principal compressive stress is vertical at least locally. In map view these faults are straight or gentle curvilinear (McGeary, 1996; Strahler and Strahler, 1994).

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Thrust faults have low dips (0^0 to 45^0) and displace the rocks on one side of the fault over the rocks on the other side of the fault. In most settings this produces an age relationship of older rocks over younger rocks. The trace of thrust faults tends to be curvilinear or sinuous, with the rocks on at least one side of the fault strongly deformed in the vicinity of the fault. High angle reverse faults (45^0 to 75^0) also placed in the rocks on one side of the fault over the rock on the other side and imply a sub-horizontal maximum principal compressive stress. Many high-angle reverse faults are associated with strike-slip faults (McGeary, 1996; Strahler and Strahler, 1994).

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(McGeary, 1996; Strahler and Strahler, 1994).

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In this study, we have used Landsat TM multi-spectral imagery and the DEM having a 30m resolution. This is satisfactory for 1:100 000 - 1:250 000 scaled paper maps. But, a 30m resolution image is not efficient for some geologic structural feature extractions, such as rivers, drainage patterns, faults considering errors and error propagation during interpretation process. We recommend the use of multi-spectral images having at least a 5 to 10m resolution image depending on the map scale and the purpose of the interpretation. This will be adequate for 1:5 000 - 1: 25 000 scaled paper maps. Today, 1 or 5-meter resolution multi-spectral images are provided by many commercial imaging companies. In these high-resolution images, the automation of interpretation would be more accurate and more reliable because of clear geometric and radiometric reflectance.

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