RECONNAISSANCE REMOTE SENSING AND FIELD STUDY OF THE DALQUEST RESEARCH AREA, PRESIDIO AND BREWSTER COUNTIES, TEXAS

By

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Introduction

Numerous studies, integrating the use of multi-spectral and thermal remotely sensed imagery, have been used for lithologic mapping (Nalbant, 1991). Other studies have incorporated remote sensing data to study urban development, distinguish flora in the field by way of spectral curve analysis, and create geologic maps (Sabbins, 1997). For example, Nalbant (1991), discussed the utility of processing techniques such as principal component analysis (PCA), selective principal component analysis (SPC), edge enhancement and hue transformation for discriminating between different lithologies. This study utilizes remote sensing methods to map lithologic units in a small, poorly mapped area in West Texas.

Extensive geologic mapping has been completed in portions of West Texas (Pause` and Spears, 1986), however, many areas have only been mapped in low resolution (Maxwell and Dietrich, 1965). The area of this study is owned by Midwestern State University and is the Walter Dalquest Research Area. Previous mapping was low resolution (Maxwell and Dietrich, 1965) and included air-photo based reconnaissance geologic maps (Brown, 1963), which are no longer available. A portion of the area is on the geologic map of the Big Bend State Park but seems to be at about the same resolution as earlier maps. These maps are not field verified (Flawn, 1966). Their production predates modern multi-spectral mapping techniques, which can be used to map surficial lithology. To date, no study has been completed using Landsat Thematic Mapper for discriminating lithologic units in the remote region that includes the Walter Dalquest Research Area.

Objectives

The purpose of this study is to produce a reflection lithologic map (RLM) of the Walter Dalquest Research Area by integrating remote sensing data with field verification. Since the area is very remote, efficacious remote sensing aided mapping is very important. It is expected that a surface RLM will not completely mirror a map based on lithostratigraphic criteria.

Geographic Setting and Regional Geology

The study area (Figure 1) covers approximately 3,000 acres in Brewster and Presidio counties. It is only accessible via a jeep-trail from FM 169 (Williamson, 2003). The northern boundary of the field area is the Alamo de Cesario creek. The southern border is the northern border of Big Bend State Park.

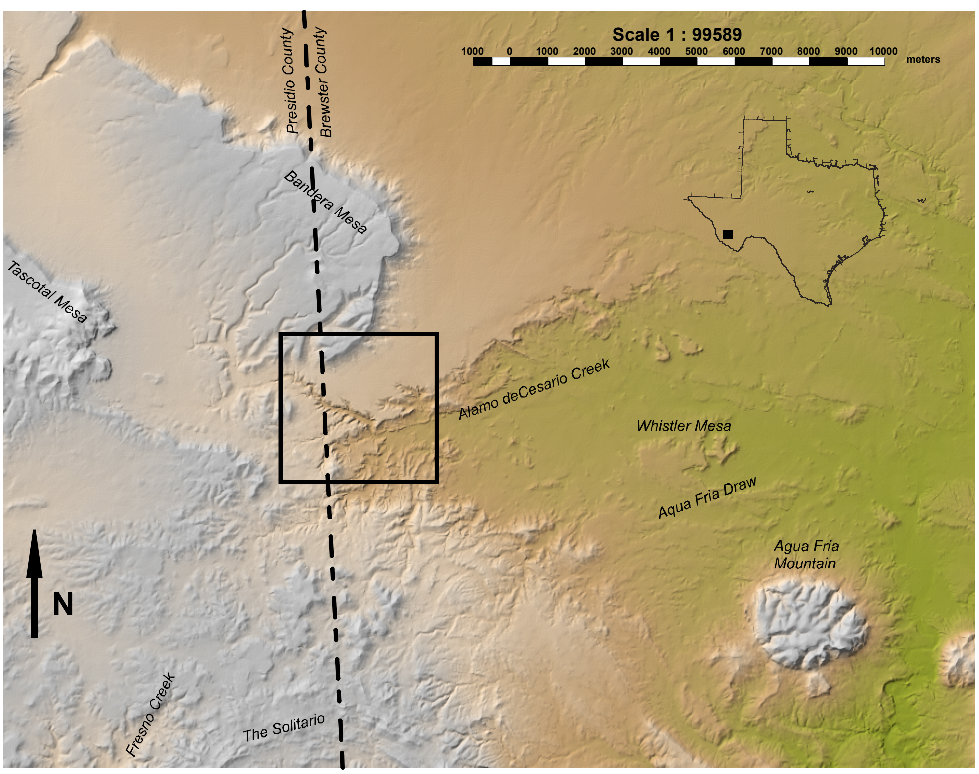

Figure 1. Location of the Walter Dalquest Study Area

Trans-Pecos Texas is part of the Basin and Range province west of the Great Plains (Price *et al.*, 1986). Laramide crustal shortening began in the Late Cretaceous, peaked in the Late Paleocene, and ended in the Eocene, however no igneous activity was associated with the event (Price *et al.*, 1986). Folding of Tertiary strata was due to either Basin and Range deformation or local collapse due to dissolution of underlying Permian evaporates or caldera structures (Price *et al*., 1986). Widespread magmatism in Trans-Pecos Texas occurred at approximately 45-32 ma. Most of the igneous rocks in the vicinity are divided into a western alkali-calcic belt and an eastern alkalic belt. There are numerous calderas that are filled with intermediate to mafic lavas (Price *et al.*, 1986). Basin and Range crustal extension resulted in continuous regional normal faulting, which began at roughly 24 ma.

Regionally there are a series of volcanic, volcaniclastic and intrusive igneous rocks that erupted from local sources (Henry *et al.*, 1998). However, older volcanic rocks were erupted from sources mostly outside of Texas. For example, the Chisos Group, that contains lavas, tuffs and tuffaceous sediments, is easily discernible in the southeast and southern part of the park. During Chisos Group time there were multiple small volcanic events. The first event, thought to have erupted at approximately 47 ma, resulted in the Alamo Creek Basalt. The second episode, at approximately 34 to 33 ma, produced the Bee Mountain Basalt, the Tule Mountain Trachyandesite and the Mule Ear Spring Tuff (Henry *et al.*, 1998). Sources also erupted near the Chinati Mountains caldera. The Morita Ranch Formation, the Mitchell Mesa Rhyolite and the Cienaga Mountains Rhyolite formed during the aforementioned eruptions. The Mitchell Mesa Rhyolite, which is also found in the study area, is the most voluminous and wide-spread ash-flow tuff and can be seen throughout the area.

The Solitario laccolith lies southeast of the study area. It formed in six phases that were part of a three-stage series from approximately 36 ma, 35.4 ma, and 35 ma. The phases are (Henry *et al.*, 1998):

1. A complex sequence of early sill laccolith and dike injection
2. Doming during intrusion of the main laccolith
3. Ash-flow eruption
4. Caldera collapse
5. Intracaldera volcanism and sedimentation
6. Late intrusions

Understanding the relationships between these different phases helps to explain the lithology of the Walter Dalquest Research Area.

Many of the Cretaceous rocks (though not those in the study area) in the Big Bend area were deformed during the Laramide Orogeny, which is evident in broad folds and faults (Pause` and Spears, 1986). Tertiary volcanic units, such as ignimbrites and tuffs, were produced during a transition period. During the Miocene, structural basins formed due to extensive normal faulting. During the Late Pliocene, the Rio Conchos-Rio Grande system breached the bolson lakes in the area creating new landforms (Pause` and Spears, 1986).

Many lithologic units have been mapped in the study area (Fisher 1979). These include various Quaternary alluvial and colluvial units, many Tertiary units including intrusive rocks, the Perdiz Conglomerate, the Tascotel Formation, the Mitchell Mesa Welded Tuff, the Duff and Pruett Formations (see Figure 2) and the Cottonwood Basalt Formation. There are also exposures of the Cretaceous aged Pen and Boquillas Formations. The Cenozoic intrusive and alluvial/colluvial rocks have both mafic and felsic mineralogy, and the Cretaceous units are dominantly sandstones and limestones (Fisher, 1979). Table 1 shows the lithologic units from the Emory-Peak Presidio Atlas Sheet.

In addition to the various lithologic units, there are two major East-West trending faults within the field area. One of these faults intersects the southern border of the thesis area. There are also several minor splinter faults that are discernible in the study area, however these splinter faults are much smaller.

Figure 2. View looking east of the central portion of the field area principally showing outcrops of the Duff and Pruett Tuffs.

Quaternary	**Quaternary Deposits (Qao) and (Qf)**	Alluvium, colluvium, and caliche on surfaces. Composed of chert, quartzite, limestone, and volcanic rocks of vesicular, aphanetic and porphyritic textures
Tertiary	**Intrusive Igneous Rocks (Ti)**	Stocks, laccoliths, sills, and dikes. Major rock types include: basalt, trachyte, rhyolite, phonolite, and latite
	Rawls Formation (Tr)	Formation consists of Porphyritic basalt, rhyolite ash-flow tuff, sandstone, conglomerate and tuff. Formation is up to 1200 ft thick.
	Perdiz Conglomerate (Tpc)	Fanglomerate of variable composition
	Tascotel Formation (Tta)	Upper material is sandstone, tuffaceous sandstone, and conglomerate. Lower material is tuff, slightly calcareous and light colored. The formation is up to 800 ft thick.
	Mitchell Mesa Welded Tuff (Tmm)	Cliff-forming ash flow, generally not welded to slightly welded. Pink to reddish-gray groundmass, but weathers dark red-gray to black
	Duff and Pruett Formations (Td) and (Tdp)	Upper part is chiefly rhyolite tuff with minor breccias and conglomerate. Mostly white but light shades of yellow and red are common. Lower portion is mostly volcanic tuff with a range of colors.
	Cottonwood Springs Basalt	Formation with up to nine or more flows , upper part vesicular, amygdaloidal. The color is reddish grey to grey or greenish black with a thickness up to 325 ft.
Cretaceous	**Pen and Boquillas Formation (Kp) and (Kbse)**	A sandy formation with some sandstone beds. Weathers yellow to yellowish-gray. Thin to medium bedded, chalky, argillaceous, limestone interbedded with gray to yellowish-gray platy marl. Marine mega fossils and microfossils are abundant.

Table 1. Description of atlas sheet stratigraphic units (adapted from Fisher, 1979)

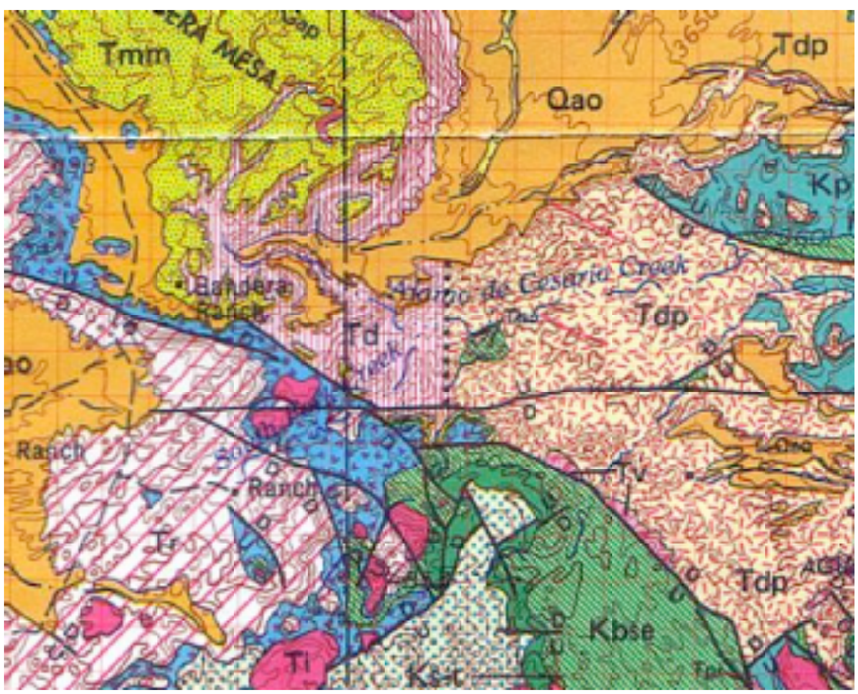

Figure 3. Section of the Emory-Peak Presidio Texas Geologic Atlas sheet (Fisher, 1979) encompassing the field area**.**

Methodology

Multi-Spectral Analysis and Image Processing:

Landsat Thematic Mapper (TM) imagery was acquired through the U.S. Geological Survey. The image (path 31, rows 39-40, ID LE7031039040002313) was acquired November 9, 2002. The image was rectified and georeferenced prior to acquisition. Landsat TM imagery was analyzed with several methods. Figure 3. Is a 432 false color infrared image that is positioned on the center of the field area.

In addition to the 432 false color image (Figure 3), a 123 Principle Components image (Figure 4) was analyzed. Multiple band combinations were inspected to look for good lithologic differentiation. From these images a Reflection Lithology Map (RLM) was defined where outcrop patterns were marked on an overlay in Canvas (Figure 6).

Reflection lithologic outcrop patterns were created by using hand samples and thin sections in conjunction with the 123 PCA and 432 false color images. The 123 PCA and 432 images were inspected and compared to obtain the best reflection differences for each of the lithologic units. Most of the outcrop patterns were created from the 432 image, but for particularly difficult areas the 123 PCA was used because this technique provided better lithologic breaks for the lighter colored units. The thin sections and hand sample analyses were used to support the mapping techniques. Thin sections and hand samples provided a basic knowledge of lithology and was helpful in creating the best defined outcrop pattern.

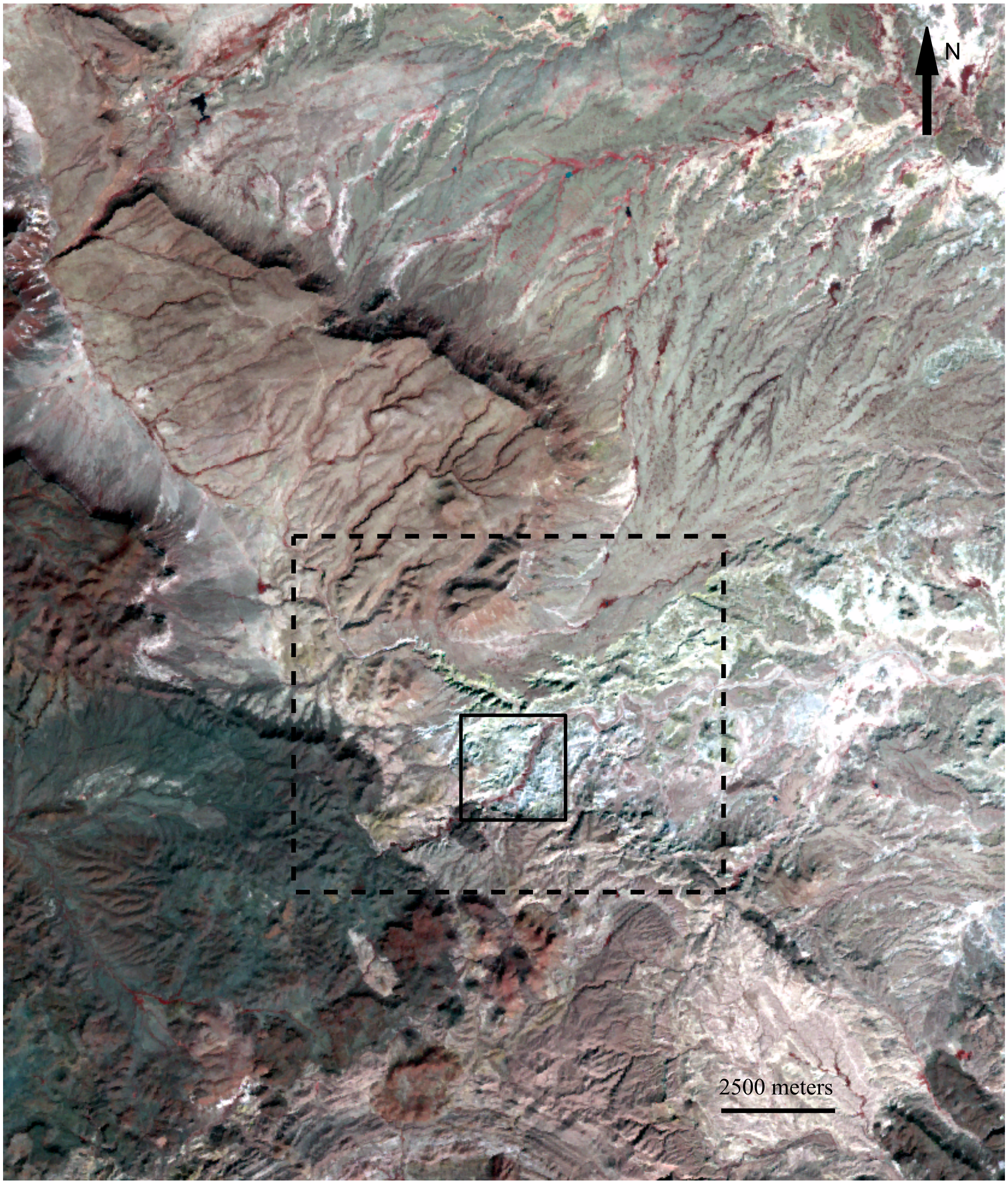

Figure 4. 432 RGB false-color image (with a Gaussian histogram stretch). Solid box shows approximate area of foreground of photograph in Figure 2. Dashed box shows study area.

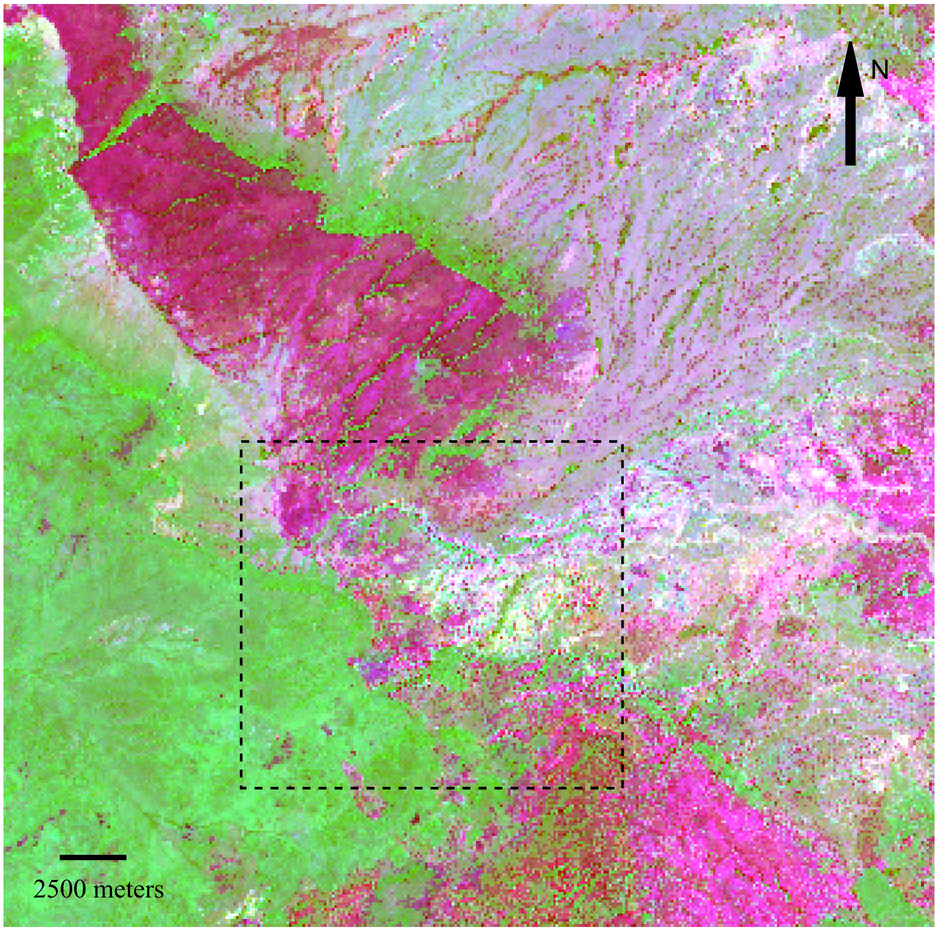

Figure 5. A 123 Principle components (PCA) image. Dashed line shows study area.

Hand Sample Analysis

In order to survey the surface lithologies in a small portion of the field area, samples were taken on a field transit. The samples were taken and locations were recorded with a Magellan Meridian GPS unit. Table 2 is a description of hand samples. The photographs in appendix A represent the samples as viewed in the field (Figure 6). The photos were taken in natural light.. A description of the samples taken from each point is in Table 3.

Point 67 & 79	J-10 Flow aligned Rhyolite
Point 68	J-2 Cream colored Tuff
Point 69	J- 8 Aphanetic Intermediate Flow
Point 70	J-8 Aphanetic Intermediate Flow
Point 71	J-6 Limestone with Dissolution Features
Point 72	J-6 Buff Limestone
Point 73	J-1 Intermediate Basalt
Point 74	J-7 Yellow Opal
Point 75	J-5 Amygdoloidal Basalt
Point 76	J-4 Black Vitrophere
Point 77	J-3 Buff to Peach colored Rhyolite
Point 78	J-9 Cream colored Rhyolite

Table 2: Sample Descriptions Correlated to GPS Points

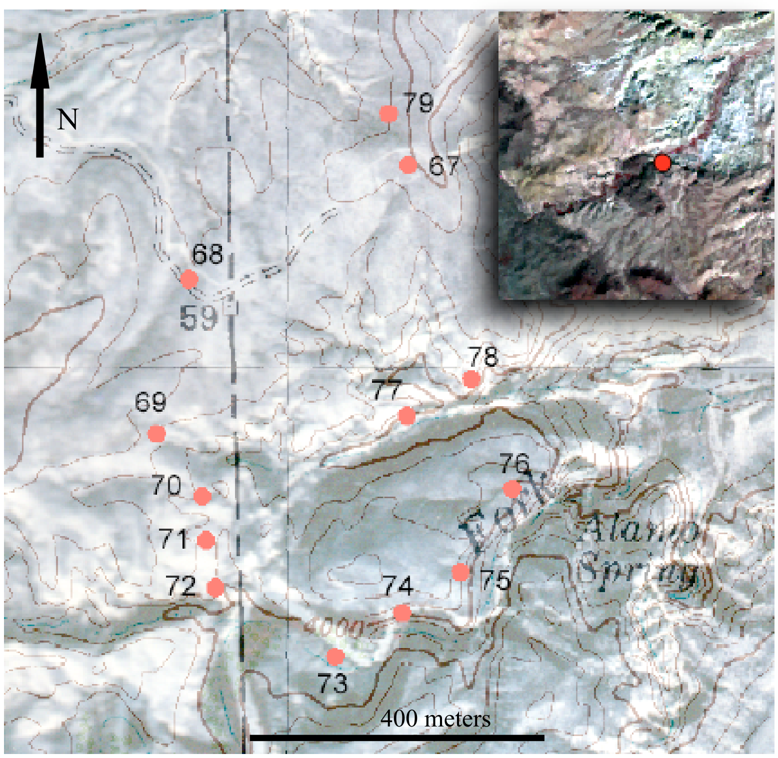

Figure 6. Topographic map section of the field site overlain by GPS points (Appendix A) of samples. Red dot in inset shows position of Alamo Springs. Compare inset to Figure 4. CI=20 ft.

Sample J-1	Black to purplish brown colored rock with aphanetic texture. Some small crystals of mafic origins are present and can be discerned with a hand lens.
J-2	Creamy colored tuff with minor mafic phenocrysts visible.
J-3	Buff to peach colored aphanetic rock. Minor bands are visible.
J-4	Black vitrophere with slightly glassy to waxy luster. Conchoidal fractures evident.
J-5	Amygdoloidal Basalt with quatrtz infused vesicles. Basalt is slightly purplish to dark brown indicating intermediate to mafic origins.
J-6	Buff colored limestone with small calcite veinlets. Dissolution features are easily visible without magnification.
J-7	Yellow to yellow-green opal with waxy luster and conchoidal fracture.
J-8	Dark brown to black colored aphanetic sample with some minor mafic crystals.
J-9	Cream, white and yellow aphanetic rock thought to be a rhyolite.
J-10	Flow aligned Rhyolite with bands of red, white and cream. Liesa Gang banding evident.

Table 3. Hand sample descriptions (see Appendix A for specimen figures).

Thin Section Analysis

Thin section analyses were used to correlate hand samples with remote sensing imagery. Thin sections are labeled J1-J10 and are in Appendix B. The descriptions are in Table 4.

Sample J-1	Mafic colored groundmass with interstitial mafics found in thin section. Rock is inferred to be in the in intermediate range, alkalic in nature.
J-2	Ash flow tuff with quartz and feldspar crystals. There are some oxidized biotite crystals as well as a few bubble wall shards. This is inferred to be a crystal vitric tuff.
J-3	Flow banded rhyolite with dense spherulitic groundmass. Both quartz and plagioclase phenocrysts are present with minor alkalic amphibole crystals.
J-4	Dark altered vitrophere with altered mafics.
J-5	Mafic rock with mafic rich groundmass. Olivine in the sample has been completely altered. Large plagioclase lathes are also present as amygdules. This rock is inferred to be an amygdoloidal basalt.
J-6	Buff colored limestone with microfossils throughout.
J-7	Opal found infilling amygdules of a vesicular basalt, yellow color.
J-8	Flow aligned plagioclase is easily discernible, with altered mafics such as pyroxene. It is pilotaxitic with titan augite in the matrix. It is inferred to be of intermediate alkalic lava type.
J-9	Flow banded spherulitic groundmass can be discerned with interstitial iron-oxide mafics. The coalescing spherulites post date the flow. There are embayed quartz phenocrysts with alkali feldspar along the flow bands. There is also an alkalic amphibole present in the groundmass This is inferred to be a quartz-ferric peralkaline rhyolite.
J-10	Groundmass contains cloudy spherulites and coalescing micro-poikilitic quartz, also known as snowflake texture. There is flow lamination with alkali phenocrysts, sanadine, present. This rock is inferred to be a flow-banded rhyolite.

Table 4. Thin section descriptions

Results and Discussion

Mapping

Figure 7 shows the RLM that was created using multi-spectral techniques and image processing techniques such as histogram stretching. Reflection lithologic units are mapped and numbered and Table 5 summarizes the matches with the atlas sheet lithostratigraphic units.

Unit	Matches
1	Rawls Formation
2	Tascotel Formation
3	Qal
4	Tascotel Formation
5	Duff Formation
6	Mitchel Mesa Formation
7	Qal
8	Qal
9	Pen Formation
10	Pen Formation
11	Boquillas Formation
12	Duff/Pruitt Formation - Lower member
13	Tertiary Igneous unit
14	Tertiary Igneous unit
15	Tertiary Igneous unit

Table. 5. RLM /Geology matching- see Figure 7**.**

Figure 7. Satellite Image overlain by the RLM.

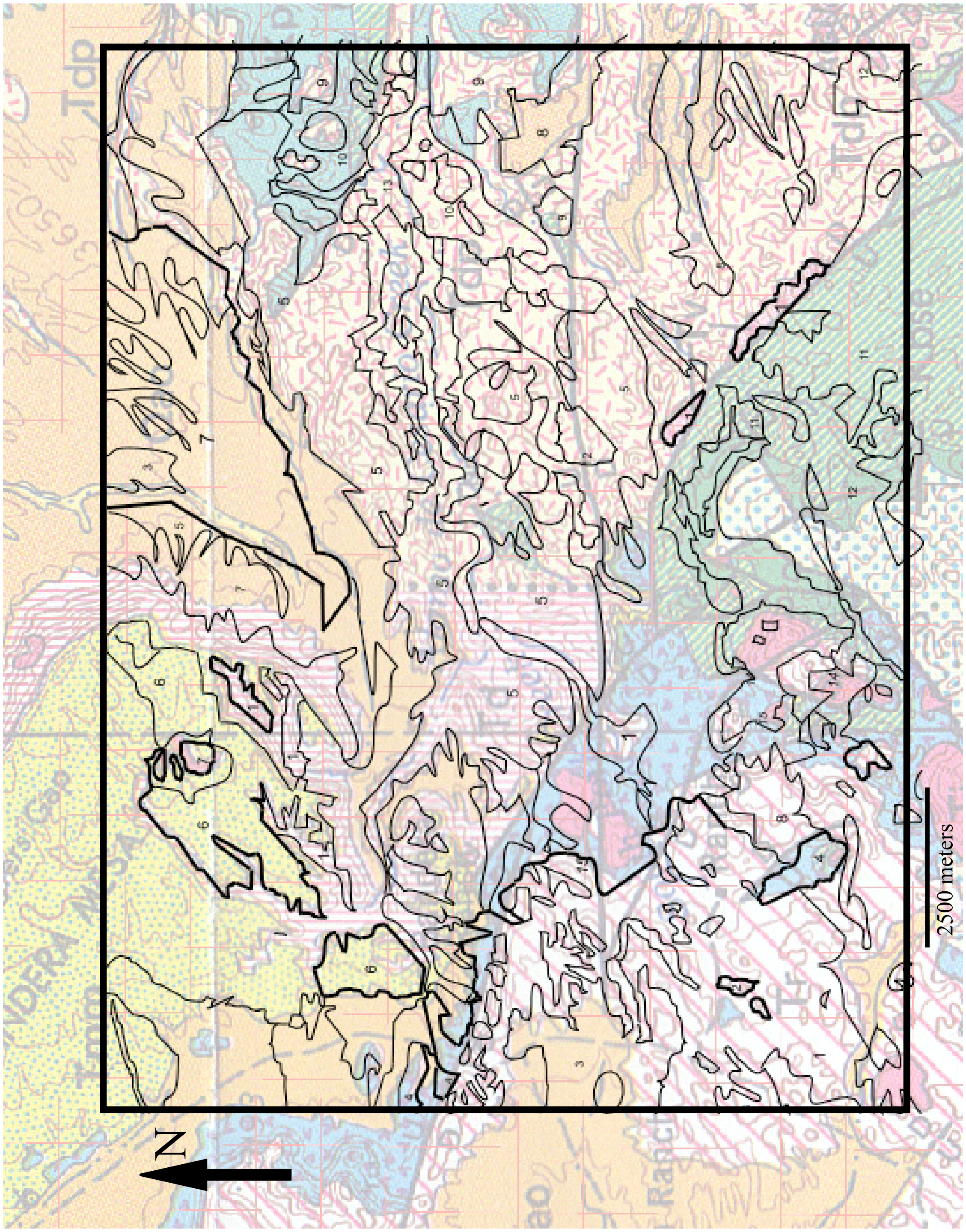

Figure 8. Geologic map (Emory-Peak Presidio Texas Geologic Atlas sheet) overlain by RLM unit boundaries.

Lithologic Observations

Figure 7 shows the RLM produced using remote sensing as well as some minor field verification utilizing thin section and sample analysis. Figure 8 shows the RLM overlaid on the appropriate portion of the Emory-Peak Presidio Texas Geologic Atlas sheet for comparison.

The Quaternary deposits (refer to both Figures 8 and 3) are mapped on the atlas sheet in orange and overlay the various lithologic units in the research area. On the RLM they are identified as units 3, 7 and 8. These units are mapped with different numbers due to the different spectral signatures that the rocks display in the satellite image. The Quaternary rocks are not only light colored alluvial and colluvial deposits, but also include the darker volcanic rocks of vesicular, aphanetic and porphyritic textures. Although the rocks are labeled differently on the RLM, they are still identified as quaternary deposits of various lithologies.

As seen in Figure 8, the RLM and the geologic atlas map patterns are quite similar in some areas. During field verification, the quaternary deposits on the surface were both dark weathered volcanic rocks as well as light buff colored silicic material. Thus mapping this formation was done by labeling the units based on their reflection differences.

The Mitchell Mesa Formation is mapped in yellow in Figure 8. On the RLM (Fig 7) the same formation appears as unit 6. The Mitchell Mesa Formation is an ash flow deposit with light colored groundmass. The light colored rocks are easily discernible by satellite imagery, therefore, the outcrop pattern of this formation matches the previous map quite well. The PCA highlighted the Mitchell Mesa Formation in a magenta color (Figure 5). This method was useful in distinguishing between the Mitchell Mesa Formation and the Quaternary deposits.

The Duff and Pruitt Formations are separated into two main groups on both the atlas sheet and the RLM. The Duff Formation can be seen as an upper group of the Duff and Pruitt Formation. It is mapped as unit 5 on the RLM. Both the atlas sheet and the RLM outcrop patterns are generally the same with a few minor exceptions. The Duff Formation is described as a rhyolitic tuff with minor breccia and conglomerate. During field verification, the Duff Formation sample was identified as a cream colored, crystal vitric tuff (J-2), based on hand sample and thin section analysis. The lower member of the Duff and Pruitt Formations were described as mostly white and yellow volcanic tuff. However, samples of this formation, taken from point 77 (see Figure 6), were identified as flow banded rhyolite with dense spherulitic groundmass (J-3) in thin section. The lower member of the Duff and Pruitt Formation is labeled unit 12 on the RLM. Since the rocks are similar in color and texture, it was more difficult to separate the upper and lower groups of this formation, hence the separate unit names. Even with this discrepancy, the outcrop patterns on both maps are close.

The Tascotel Formation is colored blue and pink in Figure 8. It is a lightly colored and slightly calcareous sandstone. It is labeled unit 4 and unit 2 on the RLM. Hand samples were taken at GPS point 72, which was classified as a buff colored limestone with microfossils (J-3). These units were easily discernible by satellite imagery (see Figure 4). The limestone beds can be seen due to their high reflectance. The outcrop patterns on the RLM match closely with the patterns on the atlas sheet.

Tertiary igneous rocks are mapped as pink units on the atlas sheet where they are not differentiated. They are labeled units 13, 14,and 15 on the lithologic map. On the atlas sheet these units are described as basalts, rhyolites, phonolites and latites Field samples taken from a small area located within the study area were shown to be intermediate basalt (J-1), amygdoloidal basalt (J-5), opal infilling vesicles (J-7) and dark altered vitropheres with altered mafic materials (J-4). Since samples were not taken from every igneous outcrop available, it is not possible to claim all igneous rocks will be of the same classification as the above. Most of these samples were taken from the field at GPS points 73, 74, 75, and 76 (see Figure 6). The outcrop patterns of both maps seem to correlate well and show as dark material on the satellite imagery (see Figure 4). The PCA separates the igneous rocks and the darker rocks of mafic and intermediate origin from the lighter rocks well. Utilizing this analysis allowed for a more complete outcrop pattern of these units. This method allows for the mafic rocks to be mapped as separate units from the lighter colored igeneous units.

The Cretaceous-aged rocks are the Pen and Boquillas Formations. These units are lithostratigraphically separated into two main portions with upper and lower members. On the atlas sheet the Pen Formation is light green in color and the Boquillas Formation is a lined green. The Pen Formation stands out as units 9 and 10 on the RLM. It is a sandstone that weathers to a white or yellow color, hence why there are separate units for the Pen Formation. The Boquillas Formation is a thinly bedded limestone. It is labeled unit 11 on the RLM. Unfortunately, Boquillas hand samples were not obtained. The outcrop pattern on the RLM matches the atlas sheet, and the light colored limestone and sandstone beds were easily distinguishable through remote sensing analysis.

The Rawls Formation is white with pink slanted on the atlas sheet (Figure 8). It is labeled as unit 1 on the RLM. This formation is typically porphyritic basalt, rhyolite ash flowtuff and sandstone. The Rawls Formation is green in the PCA image (Figure 5). Hand samples of this formation were taken at GPS points 69 and 70 (Figure 5 and Table 3) and were identified in thin section as intermediate basaltic types instead of the mafic variety (J-8). The outcrop pattern for this formation is similar on the RLM and the atlas sheet.

Conclusions

The purpose of this project was to produce a reflectance lithologic map of the field area. The final version of the RLM was produced using TM remote sensing images combined with minor field verification involving the use of hand samples and thin section analyses. The discrepancies between the previously mapped state geologic atlas sheet and the RLM are due to the fact that the atlas sheet includes geology based on photointerpretation of air photos and a variety of lithostratigraphic criteria not applicable with surface reflectance information.

The Quaternary units and the Mitchel Mesa Formation are the same on both maps. The Duff and Pruitt Formations are mapped more extensively in the lithologic map. Most of the major differences are seen in the igneous intrusive materials, which were incorrectly identified on the state atlas sheet. When surveying the study area, it was noticed that a few of the areas that were mapped as rhyolite were in fact intermediate basalts. These 'rhyolitic materials' on the atlast sheet show up as dark regions on the RLM. The atlas sheet was produced without the aid of recent technological advances.

The RLM of the Walter Dalquest Research Area is a more conclusive method when used with field verification. It provides a more complete lithologic survey of the area than that of older mapping.

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Appendix A. Petrographic Images

	**Figure 9. J1**
	**Figure 10. J3**
	**Figure 11. J2**
	**Figure 12. J4**

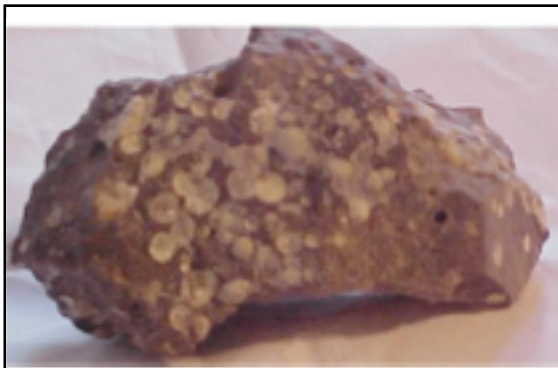
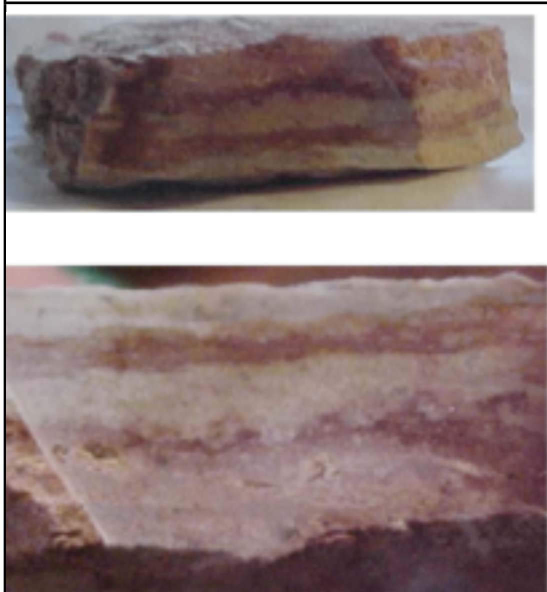
	**Figure 13. J5**
 	**Figure 14. J6**
 	**Figure 15. J7**

	**Figure 16. J8**
	**Figure 17. J9**
	**Figure 18. J10**

Appendix B Thin Sections.

The following images show thin sections in both crossed (A) and uncrossed (B) nichols.

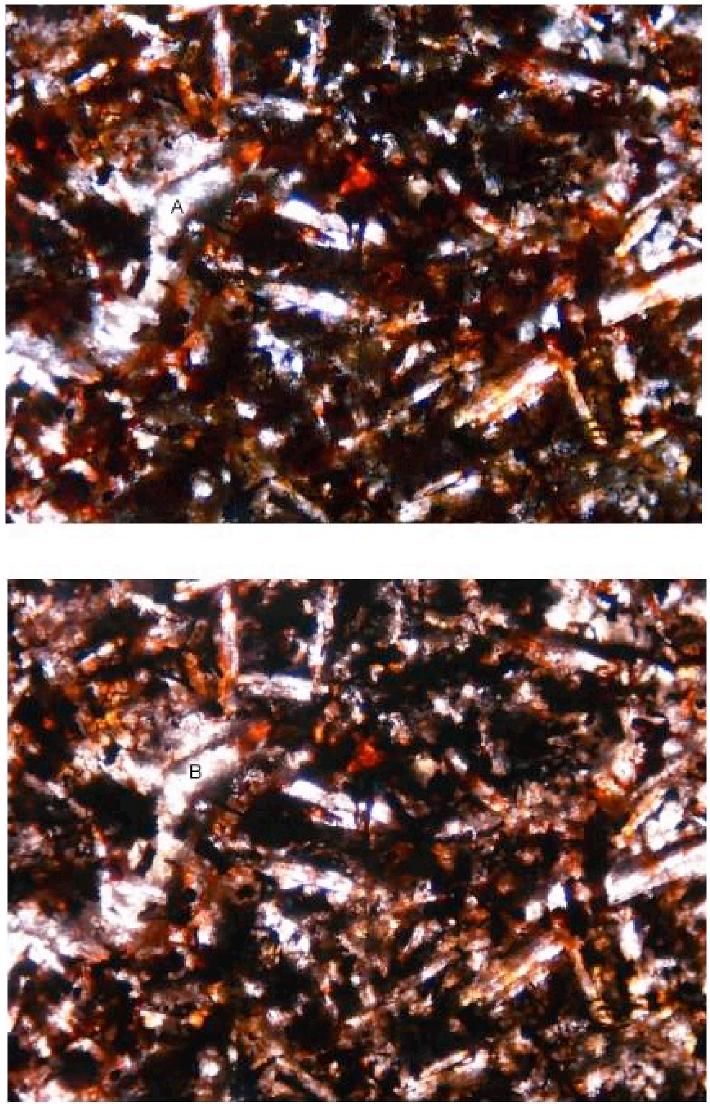
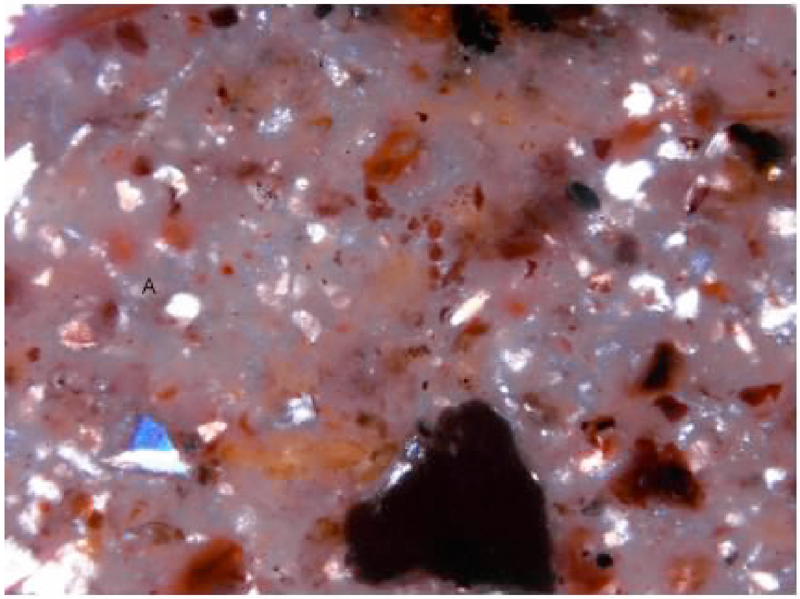


Figure 19. J1

J-2 crossed



J-2 Uncrossed

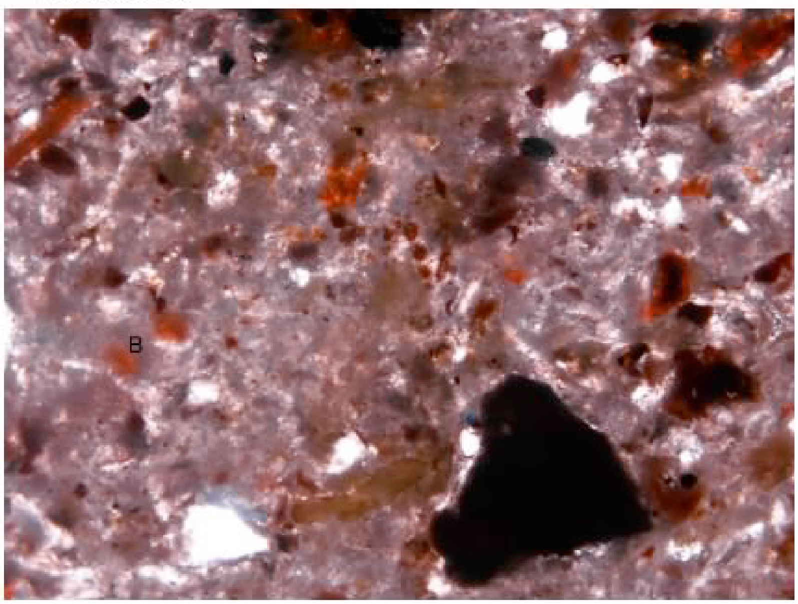


Figure 20. J2

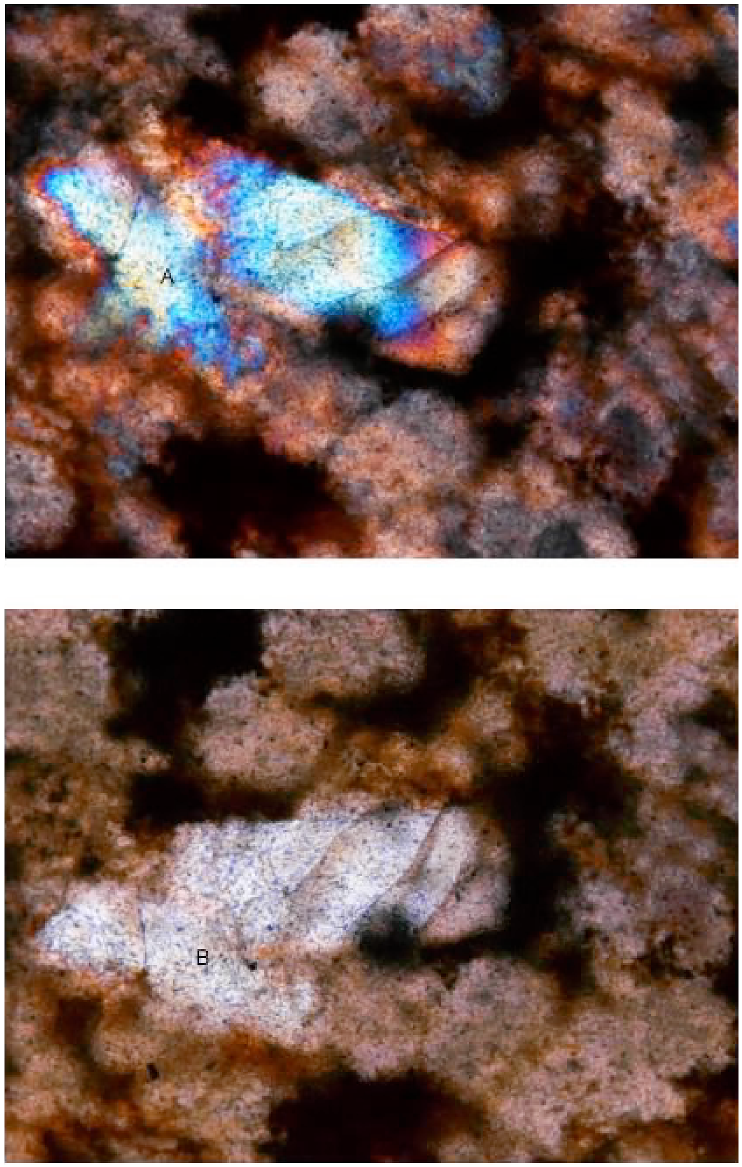


Figure 21. J3

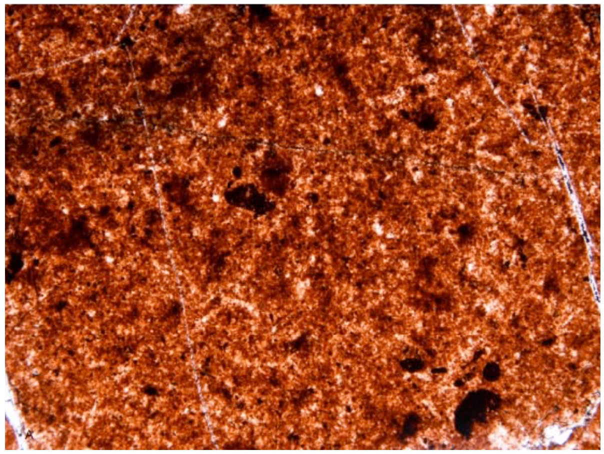


Figure 22. J4

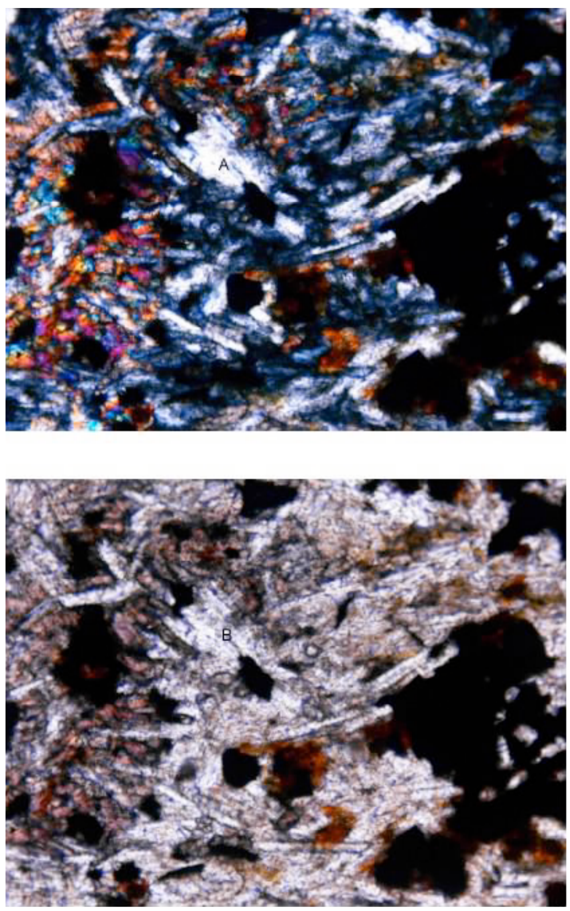


Figure 23. J5

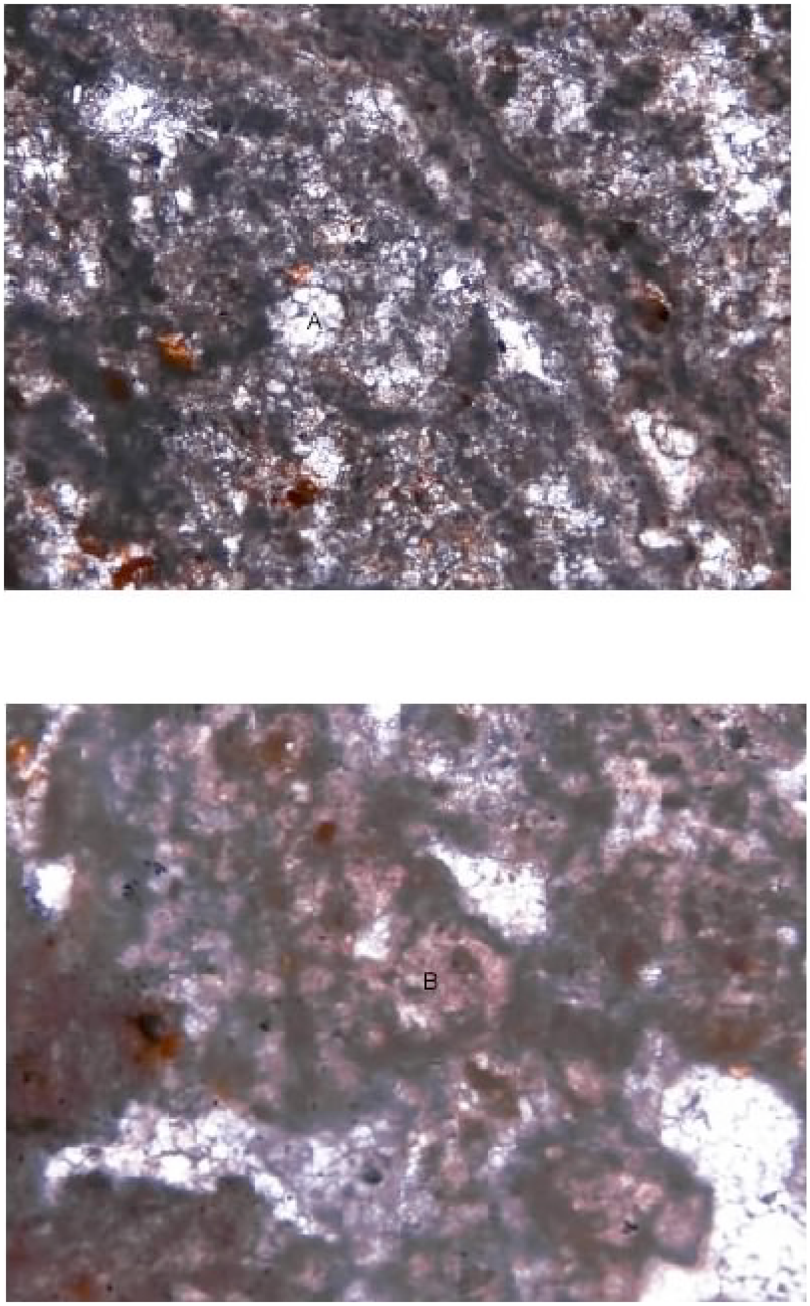


Figure 24. J6 ‘,m

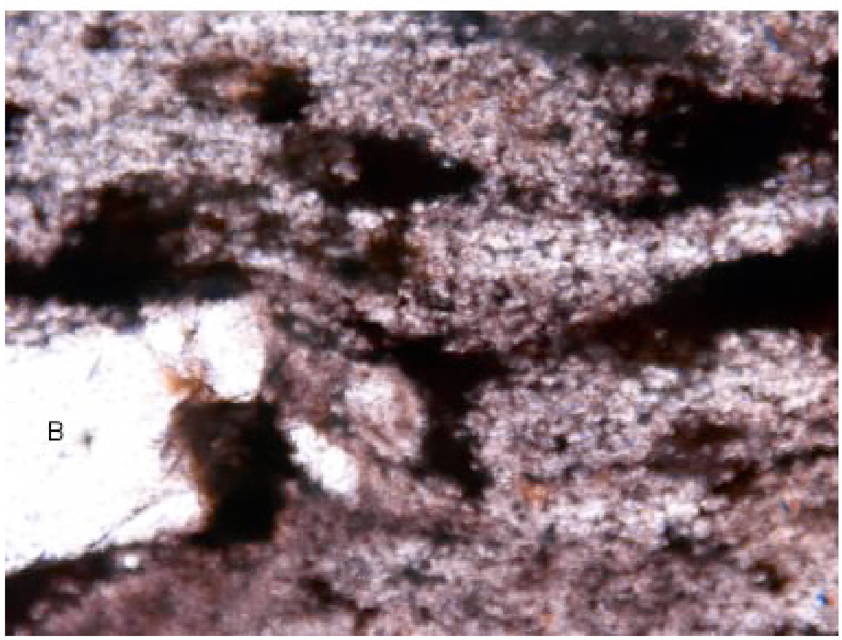


Figure 25. J8

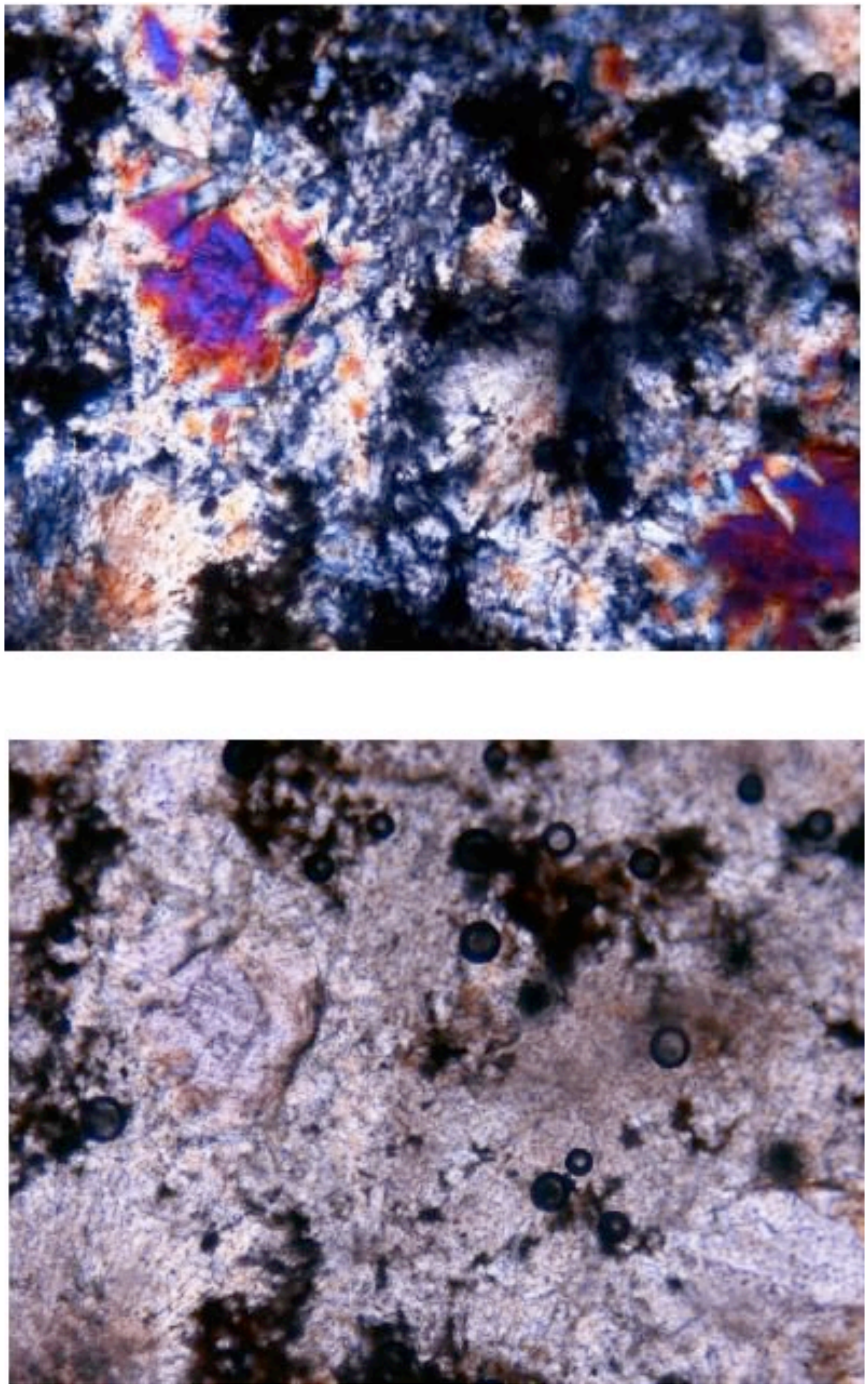


Figure 26. J9

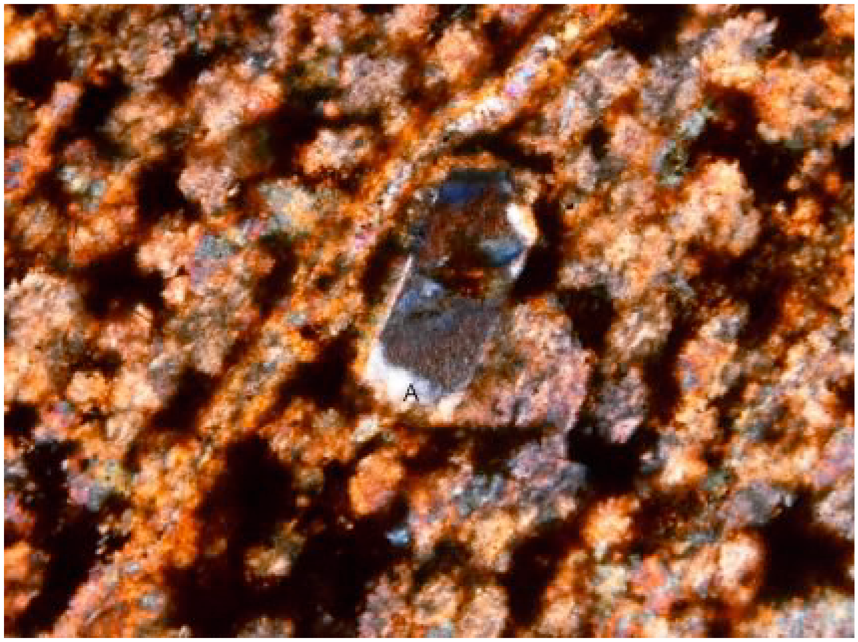


Figure 27, J10

Vita

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Reconnaissance Remote Sensing and Field Study of the Dalquest Research Area, Presidio and Brewster Counties, Texas

By Jennifer Nader, 2005

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Thesis Advisor: Dr. Arthur Busbey, Professor of Geology

The Walter Dalquest Research Area encompasses approximately 3,000 acres in both Brewster and Presidio counties in Texas. Previous mapping in this area was low resolution and included air photo based reconnaissance.

The principle objective of this study was to produce a lithologic map of the Walter Dalquest Research Area by utilizing modern multi-spectral techniques and field verification. A comparison of the previous map to the recent interpretation is also included.

A Landsat (TM) image was acquired from November 9, 2002. Multi-spectral analyses and ground verification established an outcrop pattern to compare with past geologic works.

The recent lithologic production and the past geologic map matched fairly well with some minor discrepancies. Interpretation of the lithologic breaks were verified with hand sample and thin section analyses.