AN INTEGRATED GEOPHYSICAL STUDY OF THE UNCOMPAHGRE UPLIFT, COLORADO AND UTAH

HECTOR A. CASILLAS, B.S.

Department of Geological Sciences

APPROVED:

G. Randy Keller, Ph. D., Chair

Christopher Andronicos, Ph. D.

Ann Q. Gates, Ph. D.

Charles H. Ambler, Ph. D.
Dean of the Graduate School

AN INTEGRATED GEOPHYSICAL STUDY OF THE UNCOMPAHGRE UPLIFT, COLORADO AND UTAH

By

HECTOR A. CASILLAS, B.S.

THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fulfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

Department of Geological Sciences

THE UNIVERSITY OF TEXAS AT EL PASO

December 2004

UMI Number: 1423701

ProQuest Information and Learning Company
300 North Zeeb Road
P.O. Box 1346
Ann Arbor, MI 48106-1346

DEDICATION

This Masters Thesis is dedicated to my parents Hector Alfredo Casillas Chavez and Laura Elena Holguin de Casillas, my grandparents Rogelio Holguin Richard, Francisca Rico de Holguin, Josefina Chavez de Casillas, and finally my late grandfather Isaac Ezequiel Casillas Chavira.

ACKNOWLEDGMENTS

I wish to express my gratitude to all of those that help me in making this thesis happen. First, I wish to thank Dr. Randy Keller for his expertise and support through this project providing continuous guidance during the course of this thesis and my academic term at the University of Texas at El Paso. Special thanks to the members of the thesis committee, Dr. Ann Q. Gates, and Dr. Christopher L. Andronicos, for their helpful discussion and input, as well as constructive criticism of the manuscript.

Thanks to Dr. John Seeley, Raed Aldouri, Carlos Montana, as well as the entire faculty, staff and students of the Department of Geological Sciences at the University of Texas at El Paso. Thanks are also due to the Pan-American Center for Earth and Environmental Sciences (NASA/PACES) and to the Geoscience Networking (GEON) project for the motivation and financial support throughout my entire graduate and undergraduate academic term. Finally, I wish to express special thanks to my family for their absolute moral and spiritual support.

This thesis was submitted to my committee on November 18, 2004

ABSTRACT

The Uncompahgre uplift that lies astride the Colorado-Utah border is a mostly buried tectonic feature that separates the Paradox basin to the south from the Piceance basin to the north. As part of the Ancestral Rocky Mountains orogenic belt, the structures of the Uncompahgre uplift are difficult to understand since they are largely covered by sediments and there is limited subsurface information. The uplift itself covers an area of more than 7,000 km^2 and trends northwesterly across Colorado into Utah.

Ancestral Rocky Mountains deformation began in the late Mississippian and continued until the middle Permian as recorded by facies changes and unconformities in the sedimentary section. Later on, the Laramide orogeny reactivated the structures associated with the Uncompahgre uplift. As a consequence of sedimentation, the uplift is now mostly covered by Mesozoic and Tertiary sediments. Thus, any reconstruction of the geologic history of this fault-fold uplift relies mostly on subsurface interpretations based on drill holes and geophysical data.

This thesis is an integrated geophysical and geological study of the Uncompahgre uplift region and is focused on expanding our structural understanding of the uplift and its evolution, as well as the intraplate deformation of the Ancestral Rocky Mountains. A particular feature of interest was the large gravity anomaly associated with the Uncompahgre uplift. Also, linkage to other ongoing studies to the southeast of the Uncompahgre uplift (such as studies of the Southern Oklahoma aulacogen and the Midcontinent rift) was an additional goal of this study. Remote sensing, gravity, well

logging, aeromagnetic, geologic, and seismic reflection data were employed.

Three crustal-scale cross-sections of the uplift were constructed using modeling of gravity as the platform for integration. These gravity profiles were modeled using seismic, well log, isopach and cross section data as constraints. The results required the existence of a mafic body under the Uncompahgre uplift, as well as heterogeneity in the upper crust underneath the southern gravity profile. Updated lithological structure contour surface maps for the top of the Precambrian, Cambrian, Mississippian, Pennsylvanian and Permian were produced with recent seismic, well log, cross sections, and isopach data as constraints. These maps were used to discern the structural setting of the Uncompahgre uplift and to define the geometry of density bodies used to produce the gravity models. Visualization of the data in 3D revealed that the gravity anomaly under the Uncompahgre uplift is slightly shifted to the northwest of the feature. In addition, filtered gravity and magnetic maps of the Uncompahgre uplift region were produced enhancing the different structural trends and features in the region. Connection to other studies were targeted by processing and filtering regional (Utah to Oklahoma) aeromagnetic and gravity data coupled with the earth models showed that the Uncompahgre uplift is most likely a northwestern extension of the Southern Oklahoma aulacogen. It also could be, at least in part, related to Precambrian structures in the region.

TABLE OF CONTENTS

page

ACKNOWLEDGMENTS.....iv

ABSTRACT…….....v

TABLE OF CONTENTS…….....vii

LIST OF FIGURES.....ix

INTRODUCTION.....1

GEOLOGICAL BACKGROUND.....7

PREVIOUS GEOLOGICAL AND GEOPHYSICAL INVESTIGATIONS.....14

DATA PREPROCESSING AND ANALYSIS.....30
- Gravity Data.....30
- Aeromagnetic Data.....32
- Well Log Data.....35
- Seismic Data.....38
- Remote Sensing Data.....47

PROCESSING AND INTERPRETATION 49
- GIS.....49
- Filtering.....57
- Lithological Structure Surface Contour Maps.....70
- Gravity Modeling.....77
  - GP – 1.....79
  - GP – 2.....81
  - GP – 3.....83

DISCUSSION.....87

CONCLUSIONS.....99

REFERENCES.....100

APPENDIX 1.....109
- Colorado Geological Units

APPENDIX 2.....120
Utah Geological Units

APPENDIX 3.....122
Gravity Readings

APPENDIX 4.....123
Well Logs from the Colorado Geological Survey

APPENDIX 5.....128
Formation Tops from the Colorado Geological Survey

APPENDIX 6.....129
Well logs from Jenkins (1989)

APPENDIX 7.....133
ASTER Remote Sensing Images

CURRICULUM VITAE.....137

LIST OF FIGURES

Figure 1: Location of uplifts, basins, and other features from the Ancestral Rocky Mountains....2

Figure 2: ASTER mosaic scene displaying 15 meter resolution visible near infrared (VNIR) bands....3

Figure 3: Shaded relief map of the Uncompahgre uplift region constructed from a digital elevation model produced by the Shuttle Radar Topography Mission (SRTM)....5

Figure 4a: Geologic map of the Uncompahgre uplift produced by merging two geological formation shapefiles from Colorado and Utah....8

Figure 4b: Geologic formations for the Uncompahgre uplift and surroundings....9

Figure 5: Isopach map of the interval from the base of the Upper Triassic Shinarump Conglomerate to the top of Precambrian basement....10

Figure 6: Schematic diagram representing the development of the southern portion of the Uncompahgre uplift....11

Figure 7: Location of major Precambrian age geologic provinces....13

Figure 8: Seismic survey lines covering an area approximately of 48.2 km wide and 161 km long adjacent to the Uncompahgre uplift....15

Figure 9: Location map of previous deep seismic results in the Rocky Mountain region....16

Figure 10: Crustal thickness map compiled from previous geophysical work....18

Figure 11: Upper crust velocity model showing the maximum depth of wells used for depth....19

Figure 12: Gravity model for the Deep Seismic Probe profile....20

Figure 13: Bouguer gravity anomaly map of the Colorado Plateau....22

Figure 14: Location of drill holes used to constrain computer gravity models from Jenkins (1989)....23

Figure 15: Gravity profile A-A' (Jenkins and Keller, 1989).....24

Figure 16: Gravity model B-B'(Jenkins and Keller, 1989).....25

Figure 17: Computer generated gravity model C –C'(Jenkins and Keller, 1989).....26

Figure 18: Generalized stratigraphy with estimated densities of rocks found in the central Colorado Plateau (Jenkins, 1989).....27

Figure 19: Map of the Paradox basin in Colorado illustrating the major Oil, Gas and CO_2 fields (Scott, 2003).....28

Figure 20: Gravity readings on the Uncompahgre uplift region.....31

Figure 21: Complete Bouguer gravity anomaly map of the Uncompahgre uplift region.....33

Figure 22: Total field anomaly aeromagnetic map of the Uncompahgre uplift region.....36

Figure 23: Well locations from the Colorado Paradox basin (Scott, 2003).....37

Figure 24: Reflection seismic lines used to constrain gravity profiles GP-1, GP-2, and GP-3.....39

Figure 25: Reflection seismic line from the Uinta basin.....40

Figure 26: Reflection seismic line A from the Sand Wash basin.....41

Figure 27: Reflection seismic line B from the Sand Wash basin.....42

Figure 28: Reflection seismic interpretation from the Paradox basin.....43

Figure 29: Reflection seismic line 1 from the Piceance basin.....44

Figure 30: Reflection seismic line 2 from the Piceance basin.....45

Figure 31: Reflection seismic line 1 from the San Luis basin.....46

Figure 32: GIS data workflow from the Uncompahgre uplift region.....51

Figure 33: GIS layers from the ARCGIS® 9 Uncompahgre uplift project.....52

Figure 34: 3D visualization of the Uncompahgre uplift region prepared in ARCSCENE®.....54

Figure 35: 3D visualization in ARCSCENE® of the Uncompahgre uplift complete Bouguer gravity anomaly map.....55

Figure 36: 3D visualization in ARCSCENE® of the Uncompahgre uplift complete Bouguer gravity anomaly map (looking northwest).....56

Figure 37: Complete Bouguer anomaly gravity map from the Southern Oklahoma aulacogen to the Uncompahgre uplift region.....58

Figure 38: Total field aeromagnetic anomaly map of the Southern Oklahoma aulacogen to the Uncompahgre uplift region.....59

Figure 39: Map produced by applying a high pass Butterworth (125 km cutoff) filter to the complete Bouguer anomaly data.....60

Figure 40: Complete Bouguer anomaly gravity map of the southeast United States. 4 km grid spacing. 5x5 spatial convolution filter.....62

Figure 41: Map of 3rd polynomial order surface removed.....63

Figure 42: Residual gravity anomaly map produced by subtracting the complete Bouguer gravity map (5x5 convoluted, 4 km grid spacing) with the polynomial trend 3rd order filter gravity anomaly map.....64

Figure 43: Map produced by applying a directional pass filter (0-55 degrees of azimuth removal) to the complete 3rd polynomial order 5x5 spatial convolution complete Bouguer anomaly gravity map of the Southeast United States. 4 km grid spacing.....65

Figure 44: Map produced by applying a directional pass filter (0-55 degrees of azimuth removal) to the complete Bouguer anomaly gravity map of the Uncompahgre uplift region.....66

Figure 45: Map produced by applying a directional cosine filter at 45 degrees of azimuth to the complete 3rd polynomial order 5x5 spatial convolution Bouguer anomaly gravity map of the Southeast United States.....67

Figure 46: Map produced by applying a directional cosine filter at 45 degrees of azimuth to the complete Bouguer anomaly gravity map of the Uncompahgre uplift region....68

Figure 47: Map produced by applying a 5 km upward continuation filter map to the total field anomaly aeromagnetic data....69

Figure 48: Lithological structure contour map for the top of the Precambrian basement....71

Figure 49: Lithological structure contour map for the top of the Cambrian....72

Figure 50: Lithological structure contour map for the top of the Mississippian....73

Figure 51: Lithological structure contour map for the top of the Pennsylvanian....74

Figure 52: Lithological structure contour map for the top of the Permian....75

Figure 53: Gravity Profile 1....80

Figure 54: Gravity Profile 1. Mafic body has a 2.8 g/cm^3 density....82

Figure 55: Gravity Profile 2....84

Figure 56: Gravity Profile 3....85

Figure 57: GP-1, GP-2 and GP-3 earth models confined to 10 km....88

Figure 58: Total field anomaly aeromagnetic map from the Uncompahgre uplift region (simplified version of Figure 22 enhancing geological delineations)....90

Figure 59: Map produced by applying a 5 km upward continuation filter map to the total field anomaly aeromagnetic data (simplified version of Figure 47 enhancing geological delineations)....91

Figure 60: Map produced by applying a high pass Butterworth (125 km cutoff) filter to the complete Bouguer anomaly data. (simplified version of Figure 39 enhancing geological delineations)....93

Figure 61: Map produced by applying a directional pass filter (0-55 degrees of azimuth removal) to the complete Bouguer anomaly gravity map of the Uncompahgre uplift region (simplified version of Figure 44 enhancing geological delineations).....94

Figure 62: Updated Cambrian isopach map for of the Uncompahgre uplift region.....96

Figure 63: Updated Mississippian isopach map for the Uncompahgre uplift region.....97

INTRODUCTION

The origin of the Uncompahgre uplift is considered to be part of the Ancestral Rocky Mountain orogeny that started in Late Mississippian and continued through Middle Permian time. A series of basins and intracratonic block uplifts (Figure 1) formed the Ancestral Rocky Mountains whose development has been attributed to two different tectonic models. The first model relates the development of the Ancestral Rocky Mountains to the continent-continent collision of North America with South America–Africa producing the Ouachita-Marathon orogeny. This orogeny is considered the last suturing event to form the supercontinent of Pangaea. As a result of this collision, pre-existing zones of basement weaknesses were reactivated forming a series of basins and uplifts that define the Ancestral Rocky Mountains (Kluth and Coney, 1981). The second tectonic model differs from the first one by proposing a northeast-southwest crustal shortening along the southeast margin (late Paleozoic Andean margin) of North America caused by northeast-dipping subduction. Evidence for this Andean margin comes from Central-Mexico which contained a volcanic arc during the Pennsylvanian and Permian indicating northeast dipping subduction boundary to the south and west (Ye et al., 1996).

The Uncompahgre uplift is a mostly buried tectonic feature that separates the Paradox basin on the south from the Piceance basin on the north (Figure 2). The uplift covers an area of 7,000 km^2 and trends northwesterly across the Utah-Colorado border at the Grand-Uinta County line in Utah. It is outlined on both the northeast and southwest by major fault zones called the Garmesa and Uncompahgre fault zones, respectively

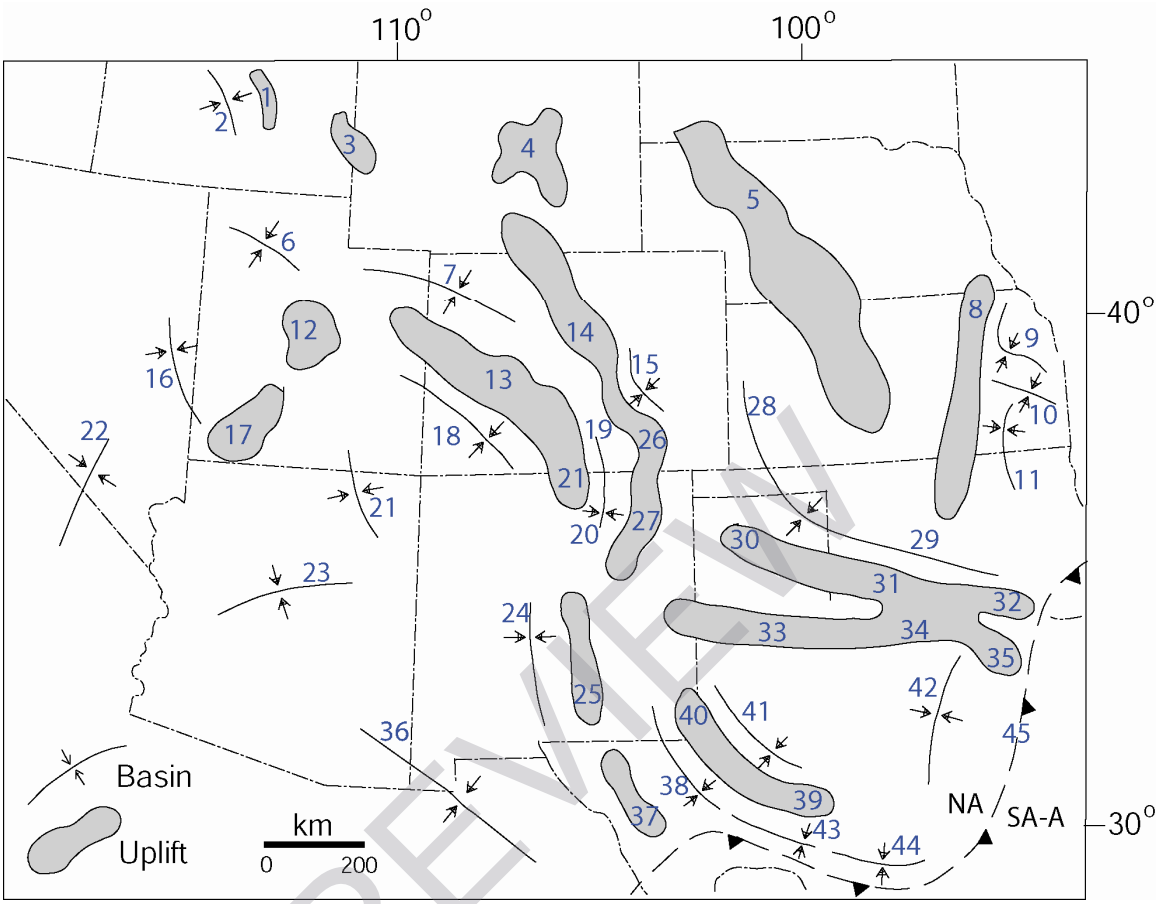

Figure 1. Location of uplifts, basins, and other features from the Ancestral Rocky Mountains. 1. Copper basin uplift; 2. Wood River basin; 3. Bannock highland; 4. Pathfinder uplift; 5. Central Kansas uplift; 6. Oquirrh basin; 7. Piceance Basin; 8. Nemaha Ridge; 9. Forest City basin; 10. Bourbon arch; 11. Cherokee basin; 12. Emery uplift; 13. Uncompahgre uplift; 14. Frontrange uplift; 15. Denver basin; 16. Ely basin; 17. Piute uplift; 18. Paradox basin; 19. Sangre de Cristo basin; 20. Rowe-Mora (Taos trough) basin; 21. San Luis Highland; 22. Bird Springs basin; 23. Arizona sag; 24. Orogrande basin; 25. Pedernal uplift; 26. Apishapa uplift; 27. Sierra Grande uplift; 28. Hugoton embayment; 29. Anadarko basin; 30. Amarillo uplift; 31. Wichita uplift; 32. Criner Hills uplift; 33. Matador arch; 34. Red River uplift; 35. Muenster arch; 36. Pedregosa basin; 37. Diablo platform; 38. Delaware basin; 39. Fort Stockton-Ozona "high"; 40. Central basin platform; 41. Midland basin; 42. Fort Worth basin; 43. Val Verde basin; 44. Kerr basin; 45. Marathon – Ouachita thrust belt (modified from Kluth, 1986).

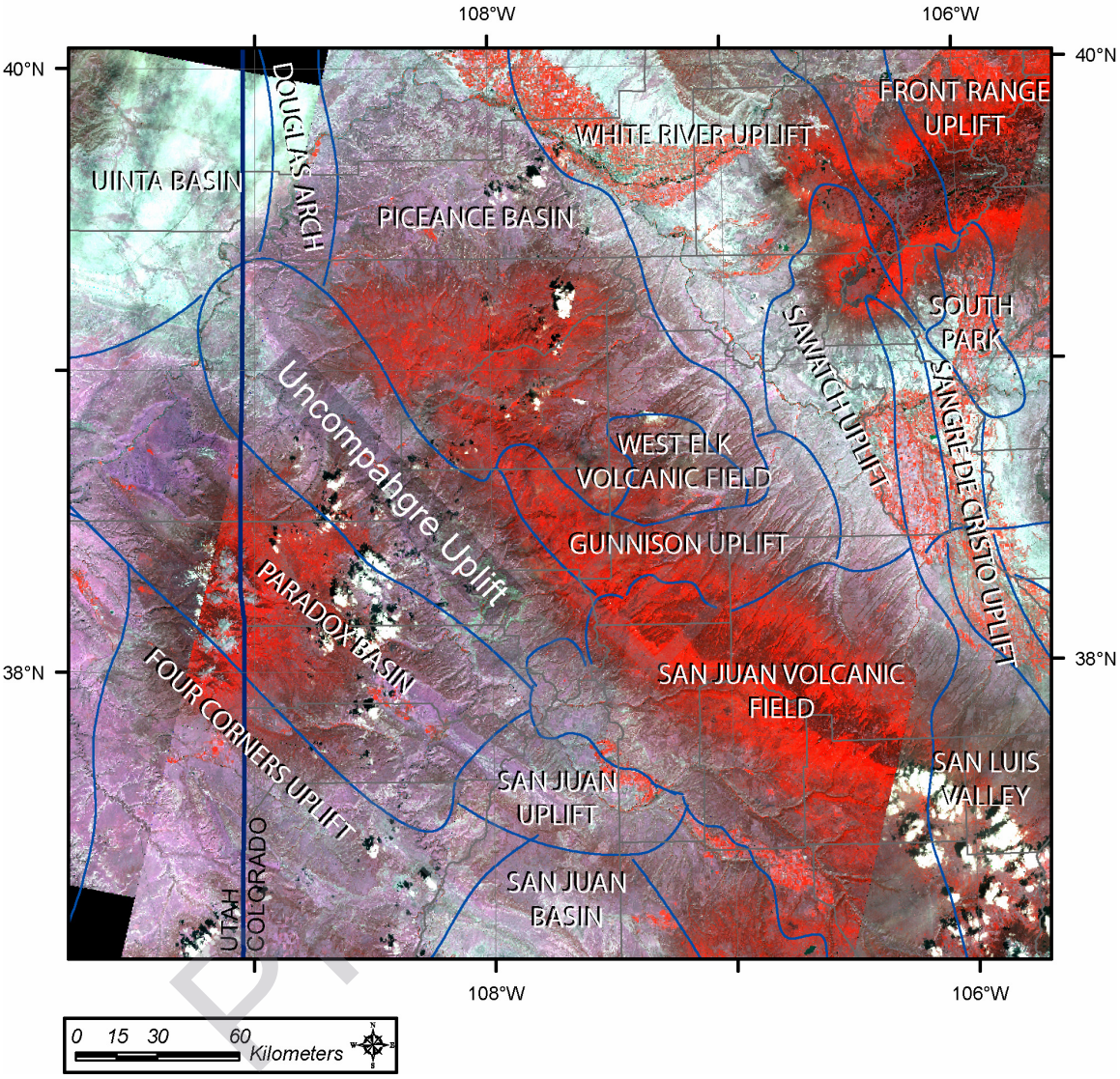

Figure 2. ASTER mosaic scene displaying 15 meter resolution visible near infrared (VNIR) bands (band combination 1-2-3). Blue lines bound the different geologic features around the Uncompahgre uplift region (outlines of the geological features are modified from Tweto, 1980).

(Stone, 1977).

On the north, the Uncompahgre uplift is bounded by the Piceance basin (Figure 3) formed mainly in the Tertiary. The Piceance basin extends from a thrust belt in north-central Utah on the west, to the southern Park Range and Sawatch uplift in northwestern Colorado on the east. The northern boundary of the basin is defined roughly by the Uinta Mountains, and the southern boundary is located along a line north of the axis of the Uncompahgre uplift (Spencer, 1993).

Bounding the Uncompahgre uplift on the south, the Paradox basin is well known for the interesting salt structures that it contains. The deepest part of the basin lies immediately adjacent to the uplift, having stepped down structurally in a series of half-grabens from the western and southwestern shelves (Baars and Stevenson, 1986).

The focus of this study is to expand our structural understanding of the uplift and its evolution, as well as the intraplate deformation of the Ancestral Rocky Mountains. A particular focus of this project is the large gravity anomaly associated with the Uncompahgre uplift. Furthermore, linkage to other ongoing studies at the University of Texas at El Paso of geologic features southeast of the Uncompahgre uplift, such as the Southern Oklahoma aulacogen and the San Juan Mountains, is an additional goal of this study. Remote sensing, gravity, well logging, aeromagnetic, geologic, and seismic reflection data were processed and integrated in this study. Specifically, gravity models integrated with well log, aeromagnetic, reflection seismic, remote sensing, and geologic data provided key data constraints along the Uncompahgre uplift. This integration of

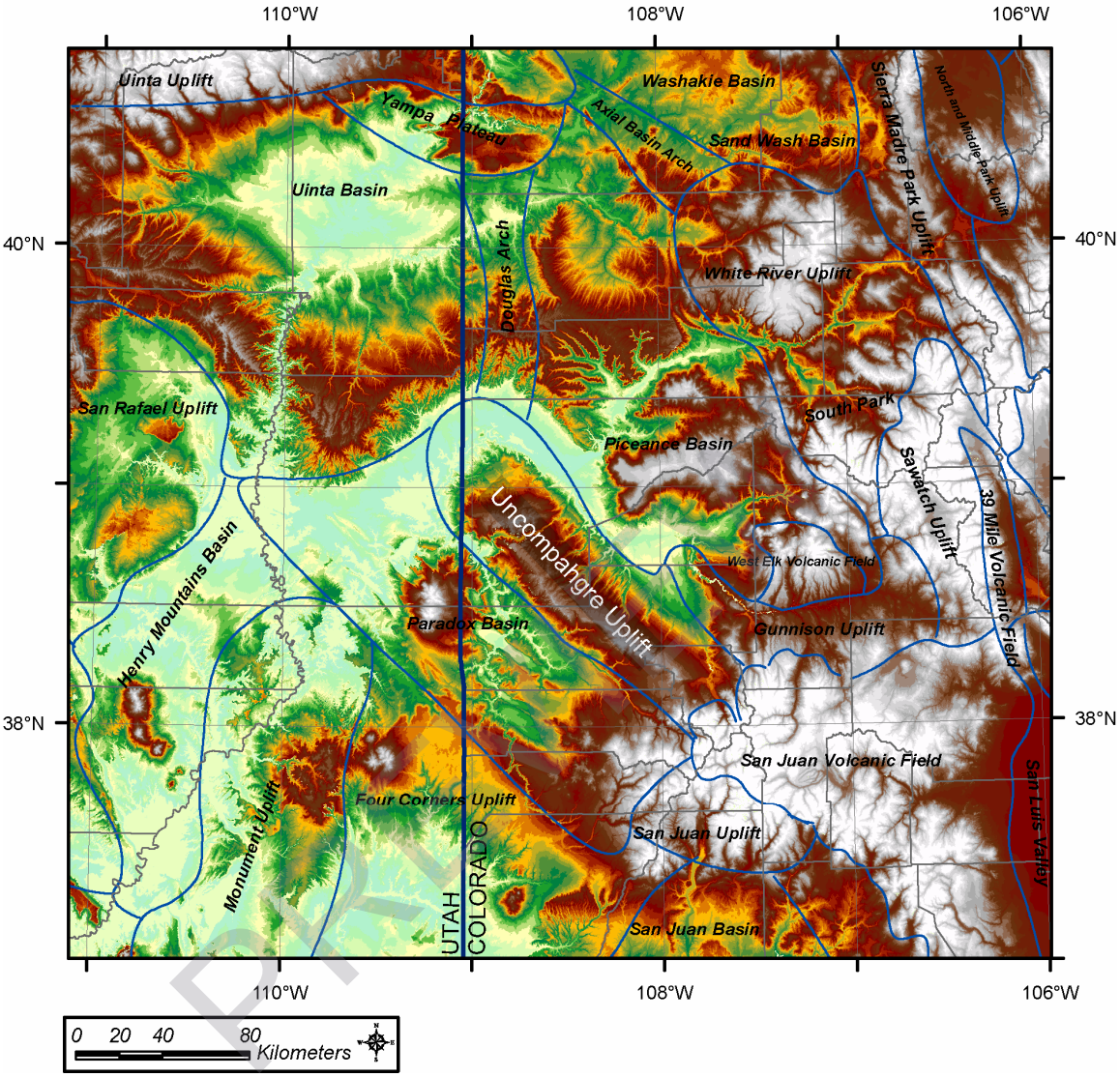

Figure 3. Shaded relief map of the Uncompahgre uplift region constructed from a digital elevation model produced by the Shuttle Radar Topography Mission (SRTM).

data will decipher whether adjacent geological features are contributing to the high gravity anomaly associated with the Uncompahgre uplift and will help determine if the uplift is a northwestern extension of the Southern Oklahoma aulacogen.

GEOLOGICAL BACKGROUND

An early step in this study was compiling a geologic map of the area from United States geologic shapefile maps of Utah and Colorado (Figures 4a and 4b).

According to Stone (1997), the first recognizable tectonic activity in the Uncompahgre uplift region initiated in late Precambrian time, with left-lateral wrench movement along the Uncompahgre fault zone to the south and the Garmesa (Figure 5) fault zone to the north. This event was apparently followed by a period of relative quiescence, as no important tectonic activity is reflected in the early Paleozoic marine rocks around the periphery of the uplift.

In addition, Stone (1977) states that the main phase of deformation in the Uncompahgre uplift took place during the Pennsylvanian and Permian, when approximately 3 km of coarse Hermosa and Cutler Formations arkose was dumped southward into the Paradox basin along the Uncompahgre fault zone (Figure 5). Pennsylvanian and Permian facies change from normal marine carbonates to non-marine red beds and clastics toward the central uplift along both its flanks, reflecting this tectonic uplift event.

In Colorado, Baars and Stevenson (1986) argue that the southeastern termination of the Uncompahgre fault is marked by the Ridgeway fault, an east-west trending fault with normal and strike-slip displacements that offsets the structure left-laterally to the east. (Figure 6). These authors argue that divergent, dextral strike-slip faulting (Figure 6a) during the Pennsylvanian Ancestral Rocky Mountains orogeny was reactivated along

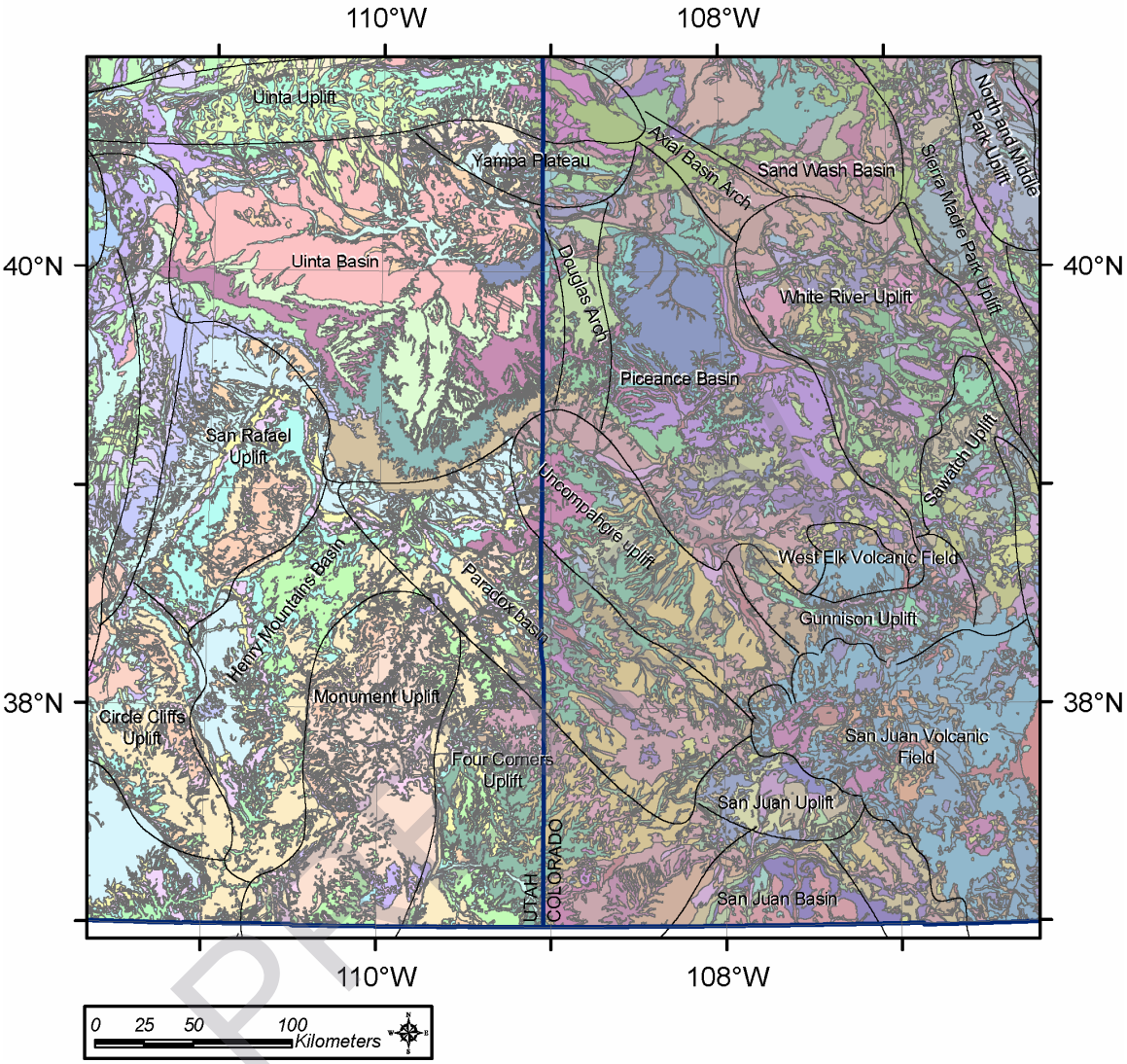

Figure 4a. Geologic map of the Uncompahgre uplift produced by merging two geological formation shapefiles from Colorado and Utah. Refer to Figure 4b, Appendices 1 and 2 for geologic formation descriptions (modified from Scott, 2003; Hintze et al., 2000).

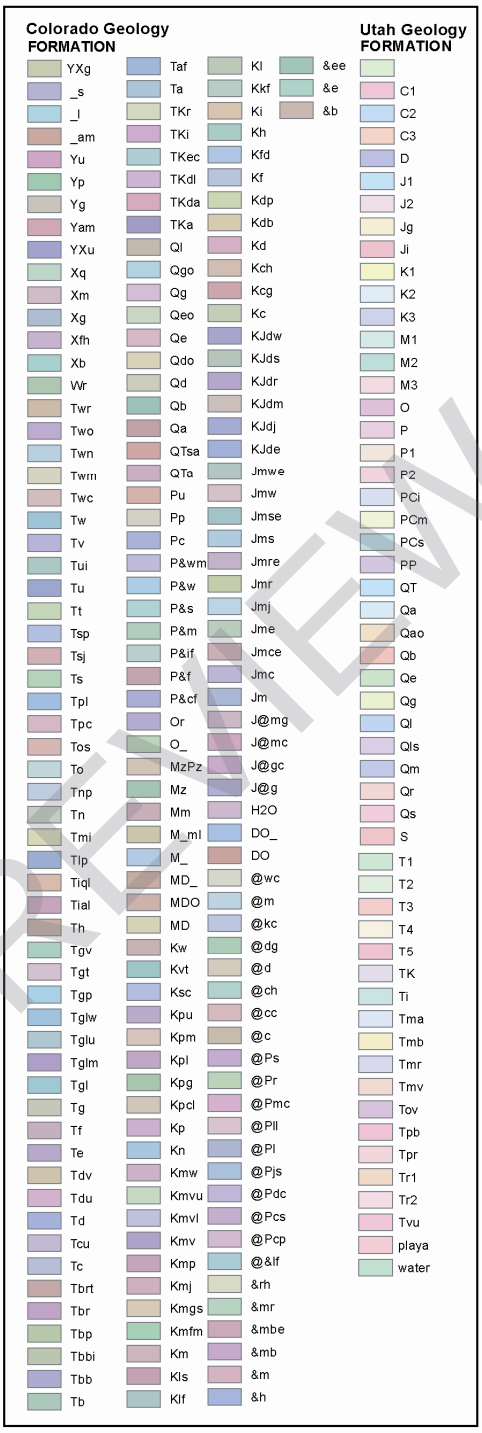

Figure 4b. Geologic formations for the Uncompahgre uplift and surroundings. (See Figure 4a, Appendices 1 and 2).