BRITTLE TERTIARY DETACHMENTS IN THE SPECTER RANGE, SOUTHERN NEVADA, AND THEIR IMPLICATIONS FOR GROUNDWATER FLOW SOUTHWARD FROM THE NEVADA TEST SITE

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B.S. Geology, SUNY Oswego, 2009

Submitted to the Graduate Faculty of

Arts and Science in partial fulfillment

Of the requirements for the degree of

Master of Science

University of Pittsburgh

2011

UNIVERSITY OF PITTSBURGH

ARTS AND SCIENCE

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July 25, 2011

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The Specter Range thrust (SRT), which extends from Mercury to Amargosa, Nevada, emplaces Precambrian silicic rocks of the Wood Canyon Formation onto middle Paleozoic folded rocks which constitute the regional carbonate aquifer. Field evidence suggests that the regional carbonate aquifer and underlying aquitard in the Specter Range have been thinned by nearly 35%, or 3,000 m along detachment horizons parallel or sub-parallel to bedding. Several regional detachments that generally coincide with sections of shaly or sandy beds also commonly affect hundreds of meters of adjacent beds as shown by breccia composed of granules to small boulders, as well as local large boulders and mega blocks, especially in dolomite units. Quartzose clastic confining units generally are strongly brecciated and may be unexpectedly porous and permeable.

The stratigraphically highest breccia mass is preserved only in the southern Specter Range, where it comprises tens to hundreds of meters of breccias derived mainly of Silurian and Devonian dolomite beds. In these units, brecciated throughout, the formation of breccia is highly variable with the smallest grain size commonly developed along steep, narrow zones

within coarser, massive breccia composed of mega-blocks and bedded sections cut and disrupted by numerous fractures and faults generally marked by breccias.

The detachments and related contractional structures locally affect Tertiary strata that constrain the timing of deformation between about 15 and 10 Ma. As previously recognized, transpression at a left-step along the right-lateral Las Vegas Valley Shear Zone (LVVSZ), between Mercury and Amargosa, Nevada is likely responsible for the contraction. Stratigraphic studies have shown that the LVVSZ accommodates several tens of km of movement.

The brecciated carbonate aquifer and clastic aquitard may provide fast pathways for groundwater moving from the NTS southward. Monitor wells in the vicinity of Rock Valley fault, north of the Specter Range, could provide information about southward-moving-groundwater before reaching the faulted and brecciated rocks of the Specter Range.

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PREFACE

I would like to thank the Nye County Nuclear Waste Repository Project office for funding this project for the past two years. I would specifically like to thank John Klenke, Levi Kryder, Darrell Lacy and Jaimie Walker for their input and support during my time in Nevada.

My sincerest gratitude goes to Dr. Thomas Anderson for the opportunity to work on this project. His continual guidance and support through out the past two years have been invaluable to my experience as a geologist. I appreciate his comments and suggestions which have helped me to improve this manuscript and prepare it in its final form.

Thanks to my committee members, Dr. William Harbert and Dr. Ian Skilling. Your comments and edits have helped to enhance the final quality of this manuscript. I would also like to thank those who helped me with ArcGIS and Adobe Illustrator. In particular, Alison Graettinger and Bobby Karimi helped me with figure and map generation.

I also would like to acknowledge my field assistants during my trips to Nevada, Alyssa Congero, Stephen Williams and Alison Graettinger. Your support and input during field work was greatly appreciated.

Lastly I would like to thank my family and friends for their continued support throughout, not only my academic career but my entire life. A special thanks to my mom, dad and sister, Antoinette, Chris and Lauren Williams. With out you none of this would be possible.

1.0 Introduction

This project was funded by the Nye County Nuclear Waste Repository Project Office, with the goal of better understanding the influence of brittle geologic structures on groundwater movement southward from Yucca Mountain and the Nevada Test Site. The proposed nuclear waste storage facility at Yucca Mountain in Nye County Nevada lies within the Basin and Range province adjacent to the Nevada Test Site. The test site was host to hundreds of nuclear bomb tests during the 1950s many of which were performed in the subsurface.

The study area is located approximately 70 miles northwest of Las Vegas between Mercury and Amargosa, Nevada mainly in the Specter Range north of Hwy. 95. The Nevada Test Site boundary intersects the northern part of the Specter Range 4 km south of Skull Mountain. The Specter Range is underlain mainly by strongly fractured carbonate rocks comprising part of the regional carbonate aquifer. Previously recognized, large faults such as the Las Vegas Valley shear zone (LVVSZ), Specter Range Thrust (SRT) and Rock Valley Fault (RVF), cut the folded Paleozoic strata.

Several workers have studied the carbonate aquifer (Fenelon et al., 2010; Laczniak et al., 1996; Laczniak et al., 2001; McKee, 1998; Winograd and Thordarson, 1975) as well as the structural geology (Albers, 1967; Burchfiel, 1965; Caskey and and Schweickert, 1992; Fleck, 1970; Stewart et al., 1968) of the region in great detail. Several episodes of deformation, from the Proterozoic to recent have shaped the Basin and Range province

The Basin and Range Province of western North America, distinguished by north-south trending ranges and adjacent half-grabens. The province encompasses most of Nevada, eastern California, southern Oregon, western Utah, western and southern Arizona, parts of New Mexico and northern Mexico (Fig. 1). It is bound to the west by the Sierra Nevada Mountains and to east by the Rocky Mountains.

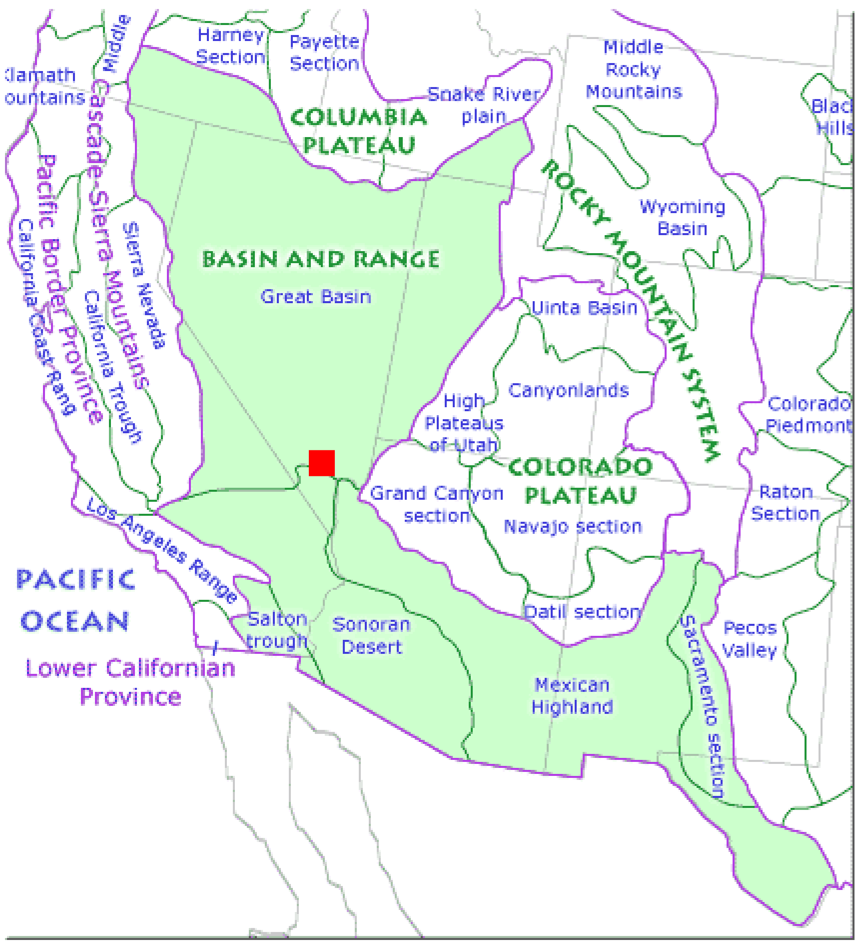


Figure 1. Major physiographic provinces of western North America. Location of field are is indicated by the red dot. Figure from (Survey, 2003).

The easterly striking SRT along which Late Precambrian units and overlying Paleozoic strata are thrust onto early and middle Paleozoic strata is a principal contractional structure in the study area, resulting from a restraining bed in the LVVSZ (Albers, 1967; Burchfiel, 1965; Stewart et al., 1968). Footwall carbonate beds record large, folds with north-trending fold hinges that are attributed to Mesozoic shortening (Stewart and Poole, 1974). Tertiary contraction is recorded in a 3-4 km wide zone, north and south of the SRT, where bedding has been rotated east-west (Plate 1).

The northeast –striking, left-lateral, RVF, separates the Specter Range to the south and the Striped Hills and Southwestern Nevada Volcanic field (SWNVF) to the north. It is an active fault which reaches depths of at least 3 km according to earthquake focal depths (O'Leary, 2000). Several north-south splays that step south cut and displace the hanging wall and footwall of the SRT.

The LVVSZ is a northwest- striking, right-lateral shear zone, along which 30 miles of offset is recorded by displacement of correlative regional structures and/or stratigraphic units (Burchfiel, 1965; Longwell, 1960; Stewart et al., 1968). East of Mercury, NV the northwest-striking trace of the LVVSZ is no longer evident and displacement observed along Las Vegas Valley dissipates. Several workers (Stewart, 1967; Stewart et al., 1968) postulate that the LVVSZ bends west near Indian Springs, resulting in transpressional structures on either side of the fault.

(Winograd and Thordarson, 1975) recognized a path of rather fast groundwater movement extending southwest from Mercury under the eastern part of the Specter Range, across Hwy 95 and continuing toward Ash Meadows (Fig. 2). (Fenelon et al., 2010) corroborated the predominately south-southwest flow paths from the Nevada Test Site through Amargosa Valley into the Ash Meadows flow system which continues on to Death Valley. The principal objective of this study has been to reveal the geologic conditions leading to the presence of “fast” groundwater pathways extending away from the Nevada Test Site.

Within the study area two suites of pre-Tertiary rock bear importantly upon the movement of groundwater: the carbonate aquifer, composed of Late Precambrian to Middle Paleozoic carbonate, underlying siliciclastic rocks of the Johnnie, Wood Canyon and Zabriskie formations that comprise the clastic aquitard. Intense brittle deformation of the siliciclastic units probably compromises their integrity as confining layers.

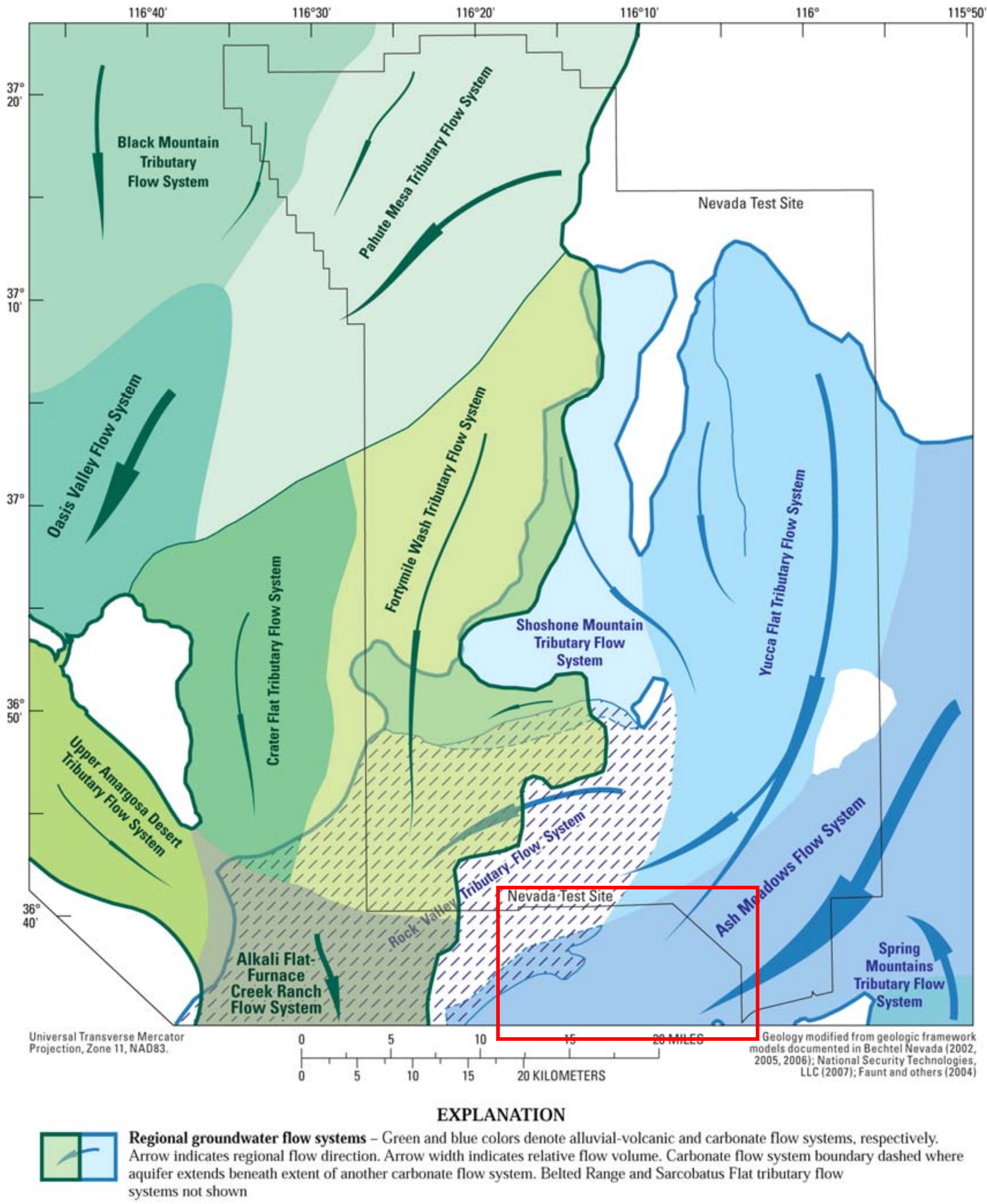


Figure 2. Map showing the distribution of flow systems and groundwater pathsways southward from the Nevada Test Site. The red box outlines the study area. From Fenelon et al., (2010).

2.0 Methods

Initially a detailed geodatabase of the field area and a literature review were completed. Following this, several field campaigns were conducted in 2010 during which structural data were collected at more than 800 locations throughout the Specter Range. Measurements were made with an azimuthal brunton compass using the right-hand rule, and compiled into appendices A-D. Over 600 digital photos also were taken and complied in appendix E. Stereographic projections and rose diagrams were used to summarize structural data and interpret relationships using Georient 10.0. Stratigraphic columns were also produced and compared with the type section to emphasize the severe thinning that occurs along bedding horizons throughout the Specter Range.

Field maps were enhanced by employing Google Earth which proved to be an invaluable tool as some areas of the field are inaccessible due to restrictions imposed by the Nevada Test Site or time constraints. The resolution of the satellite imagery compiled by Google Earth is high enough that it is possible to discern bedding. In turn stratigraphic relationships can be better defined and detachments can be mapped based upon changes in orientation, or loss of bedding completely. The Google Earth files that were produced were converted to shapefiles for use in ArcGIS 10. The new shapefiles were overlaid on a georeferenced ASTER image (Fig. 3) (Plate 2).

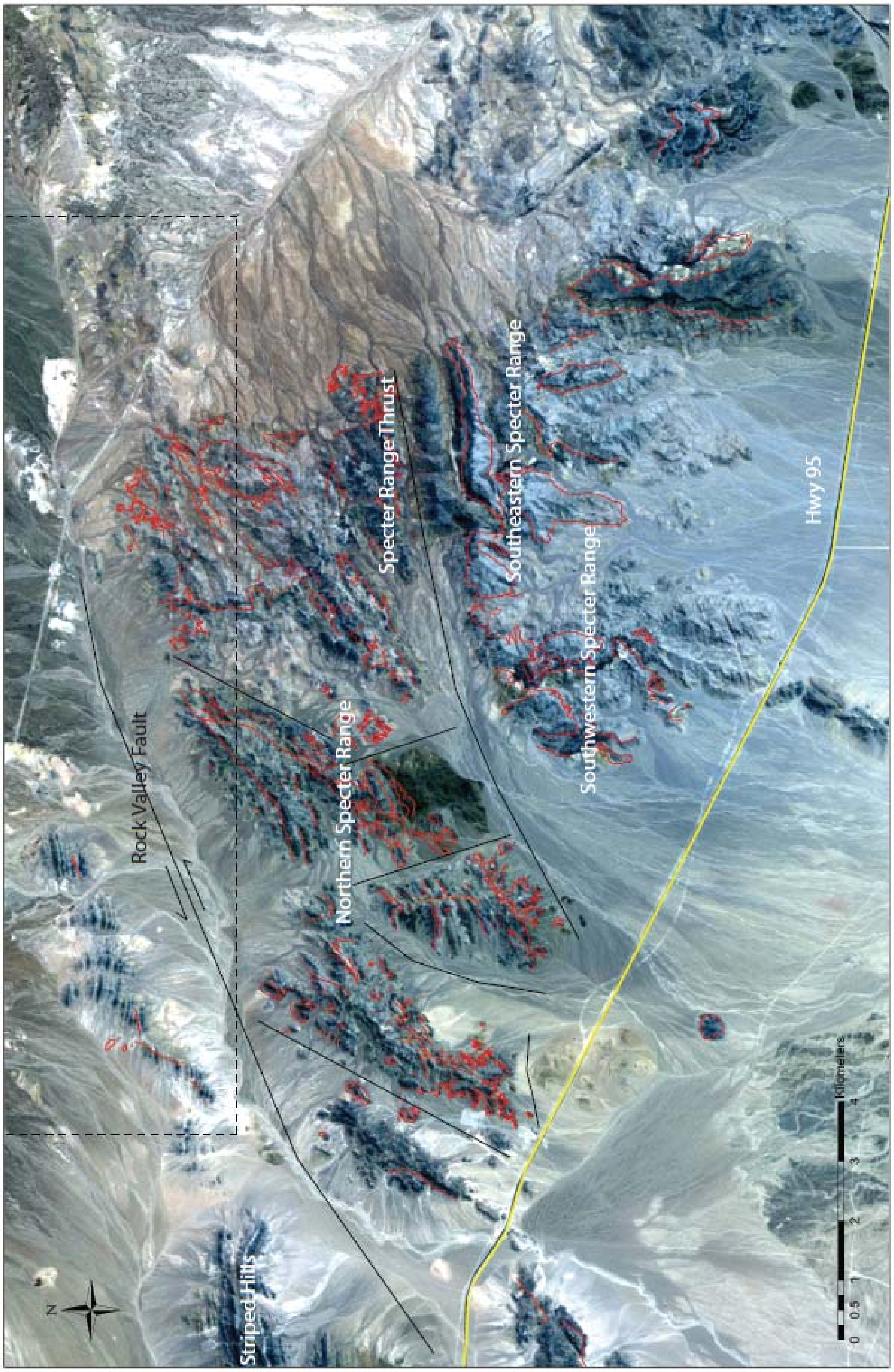


Figure 3. ASTER imagery of the study area. Major structures (RVF and its splays and the SRT) are denoted by black lines. The black dashed line denotes the Nevada Test Site boundary. Detachments are denoted by the redlines. Hwy. 95 is highlighted in yellow.

3.0 Regional Geologic Setting

Rocks of the western margin of North America including southern Nevada record multiple pulses of deformation since the break-up of Rodina in the Late Precambrian, about 750 Ma. (Stewart, 1972). From Middle Cambrian to Middle Devonian a westward thickening carbonate shelf formed in a shallow proto-Pacific Ocean. The rocks that accumulated on the continental margin are predominantly siltstones, shales, sandstones, and conglmerates that reach thicknesses as great as 6,000 m (Poole et al., 1992) . An isopach map from (Stewart, 1972) illustrates the vertical distribution of Precambrian to Lower Cambrian rocks within the field area is nearer to 2,300 m. The correlative units in the study area would be the continentally sourced, Johnnie Formation, Stirling Quartzite and the Wood Canyon Fromation. The carbonate section then began to accumulate in a shallow marine environment until the Devonian (Morrow and Sandberg, 2008; Poole et al., 1992). Rifting progressed until the Middle Paleozoic when contractional structures began to form. During the Mesozoic long episodes of convergence are recorded by igneous rocks.

After about 55 Ma Eocene extension became dominant. At 42 Ma, the west-directed Eocene event ended. After a pause of several million years southwest-directed extension began and lasted until 20 Ma. The current extensional regime commenced during the middle Miocene, 3-4 Ma later and is still active. Rocks of the Specter Range mainly record Paleozoic and Tertiary events that have complicated stratigraphic relations by offsets along normal faults and detachments that have resulted in thinning or in places elimination of units and in places complete formations.

3.1 Stratigraphy

Approximately 8,000 m of stratigraphy comprises the type section (Stewart, 1970) from Precambrian to middle Paleozoic rocks (Fig. 5). When compared to the type section, however, several units illustrated severe thinning and brecciation along their stratigraphic boundaries. The Striped Hills serves as an excellent stratigraphic type section for the carbonate aquifer and underlying clastic units from Precambrian to Devonian. Several workers have interpreted the Striped Hills has been as an overturned anticline (Sargent et al., 1970). They are separated from the main part of the Specter Range by the RVF. Bedding in the Striped Hills is very steep and its stratigraphic units are not obscured by brecciation as severely as in the central and southern Specter Range (Fig. 4).

Figure 4. Photo illustrating steep bedding measured in the Paleozoic carbonate section in the striped hills. View is looking north. The white unit is the distinctive bleached band, approximately 15 m thick near the base of the Bonanza King Formation.

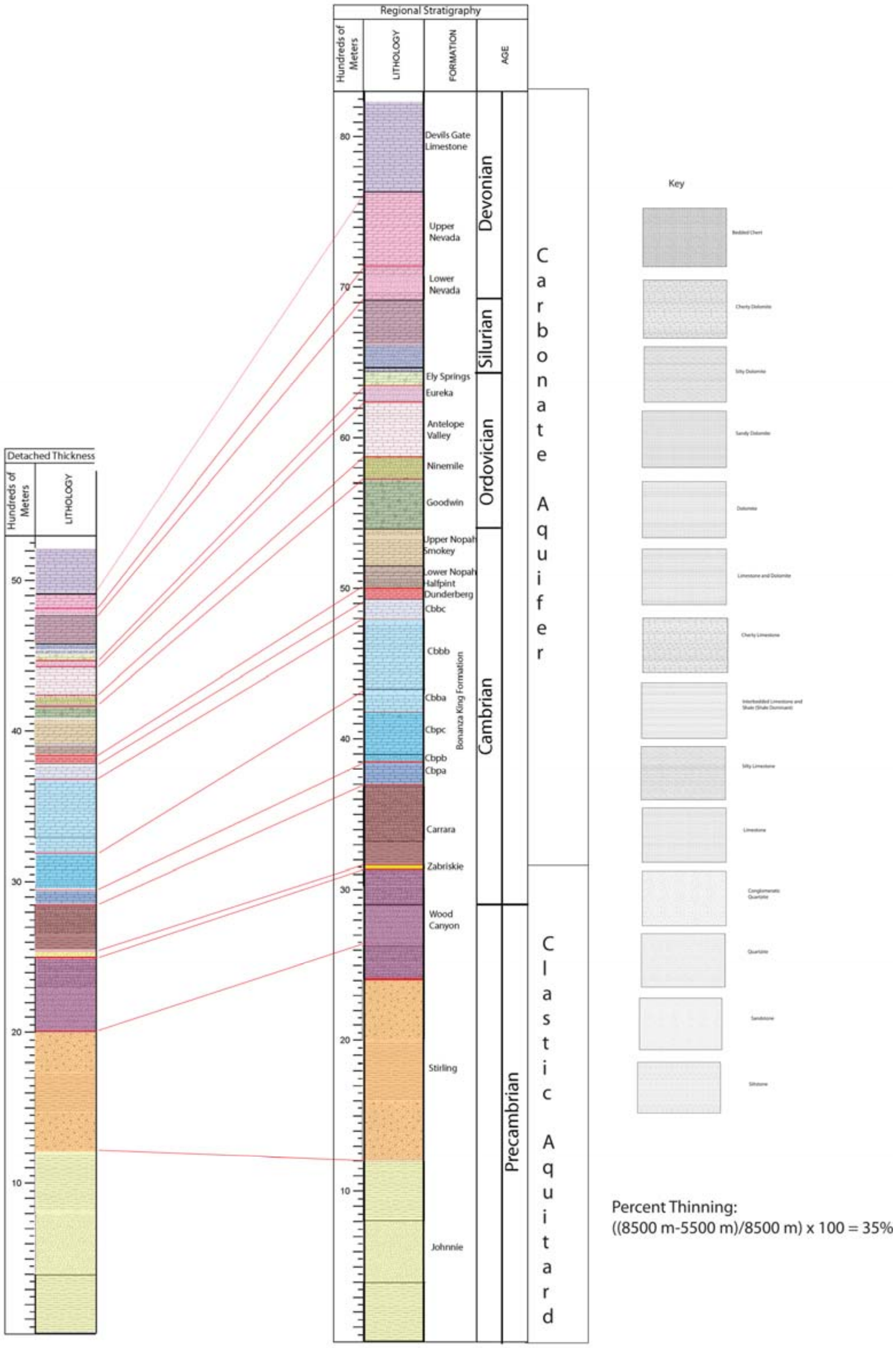


Figure 5. Regional stratigraphic column from the type section of Precambrian to middle Paleozoic rocks and their thickness post detachment in the Specter Range. Red lines horizons are detachment horizons and black lines are conformable contacts. Column was compiled from (Burchfiel, 1964; (Merriam, 1963); Sargent et al., 1970; Sargent and Stewart, 1971).

3.1.1 Precambrian

Three Precambrian age formations crop out in the Specter Range quadrangle; the Johnnie Formation, Stirling Quartzite and the Wood Canyon Formation. The Johnnie Formation is exposed in the northwestern Spring Mountains to the southeast of the study area. The lower third of the formation is composed of fine to medium-grained, weathered sand and siltstone. The upper third of the formation is composed of quartzite, sandstone, and siltstone with dolomitic interbeds (Burchfiel, 1964). The thickness of the Johnnie Formation is not known because its base is not exposed in the Spring Mountains. The type section for the Specter Range quadrangle is approximately 1,300 m and is located in the southeastern corner of the Specter Range quadrangle/northern Spring Mountains. The Johnnie Formation has a continental provenance and the first unit deposited following neoproterozoic rifting (Poole et al., 1992)

The Stirling Quartzite overlies the Johnnie Formation. The contact is marked by a siltstone bed which separates thin bedded siltstone interbedded with quartzite from massively bedded, conglomeratic quartzite (Burchfiel, 1964). It also contains local greenschist facies minerals. The thickness is the Specter Range has been measured at 300 m (Burchfiel, 1964), which crops out as several small hills south of the Specter Range proper and is located on either side of Hwy. 95. In the Spring Mountains the quartzite is almost four times as thick. Bedding is highly variable is not easily recognizable as it is often obscured by intense fractures.

3.1.2 Paleozoic

The siliciclastic Wood Canyon, 720 m thick (Sargent and Stewart, 1971; Stewart, 1970), is Precambrian to Cambrian age. The most dominant rock types are red, white and green commonly cross-bedded quartzite. Another distinctive unit of the Wood Canyon Formation is a pebble conglomerate. Grain sizes vary from pebble to cobble and are sub-angular to sub-rounded in shape (Fig. 5). Silty and sandy shale interbeds also are common throughout the formation. The top and the base of the formation are characterized by sandy dolomite units, although the lower dolomite was not found in the field area.

The largest exposure of Wood Canyon in the study area is located in the central Specter Range and contains both brittle and ductile structures. The unit is locally foliated parallel to the strike of bedding and dips 20º steeper (Fig. 6). The foliation is defined by green recrystallized micaceous shale. The foliated units are found at the base and top of the unit (Burchfiel, 1964), however the unit pictured below is probably near the top of the Formation based upon stratigraphic relationships. Field evidence suggests its detachment from the underlying Stirling Quartzite.

Figure 6. Photo illustrating fissile, foliated shale at the base of the Wood Canyon Formation. Average foliation measured 260/60. Location NAD 1983 UTM Zone 11 N 564365 4053466.

The Zabriskie Quartzite is at the top of the Wood Canyon formation. It is variably colored laminated to thick-bedded quartzite. It is also marked by distinctive scolithus burrows. The Zabriskie Quartzite is nearly 150 m feet thick just west of Specter Range and only about 30 m thick in the Belted Range to the east (Slate et al., 1999), Therefore the thickness of the Zabriskie should fall between those two values. However, in detailed field mapping, it is almost impossible to find. Furthermore the outcrops that do exist are typically severely brecciated, suggesting it has been faulted out or thinned along a detachment between the Wood Canyon Formation and the overlying Carrara Formation.

The Carrara Formation, is a slope-forming unit of interbedded limestone, siltstone, sandstone and shale (Burchfiel, 1964) transitional from the older quartzose rocks to the middle Cambrian carbonate units which comprise the carbonate aquifer. Silty, orange-weathering, limestone is the unit’s characterizing feature, making it identifiable from a distance. The top of the unit is defined by a gray limestone with orange weathered silty partings. The upper contact of the Carrara Formation is defined by the transition from siliciclastic, slope- forming rocks to massively bedded limestone and known to be unconformable.

The thickness of the Carrara Formation in the nearby Striped Hills is 500 m (Sargent et al., 1970). In the Specter Range it is only about 300 m thick (Sargent and Stewart, 1971) and at the SRT the Carrara is almost entirely missing (Plate 1, A-A’). In most places the Carrara Formation remains cohesive, with beds striking approximately E-W. However, directly beneath the overlying Bonanza King Formation, the uppermost beds are severely brecciated. Large clasts commonly retain bedding and are cemented in a calcite rich matrix

(Fig. 7). Locally near the contact with the overly Bonanza King Formation light orange, weathered Carrara carbonate is foliated (Fig. 8).

Figure 7. Brecciated Carrara Formation marking detachment along straigraphic bedding. Photo is located at NAD 1983 UTM Zone 11 N 568121 4053756.

Figure 8. Photo of foliated Carrara Formation , approximately 4 km east of the Figure 7 location near the Specter Range thrust.

The Bonanza King Formation is divided into two members (Burchfiel, 1964), each of which is subdivided into three units, whose abbreviations are listed below (Sargent and Stewart, 1971). For mapping purposes only the detached horizons are shown on the map. In some places the upper and lower members are not differentiated and are simply denoted as Cbp and Cbb. The lower is the Papoose Lake member (Cbp), whose base is commonly detached from the Carrara Formation. The lowest unit (Cbpa) is approximately 150 m thick (Sargent and Stewart, 1971) and is easily recognizable by a 15 meter thick, fine-grained, light gray, bleached, limestone unit in the middle. The remaining 135 m is massively bedded, medium to dark gray, mottled limestone. The middle Papoose unit (Cbpb) is approximately 60 m thick., It is composed of silty limestone and dolomite with silty horizons interspersed throughout its thickness (Sargent and Stewart, 1971). This unit is commonly absent probably because the silty, thin beds accommodate detachments that attenuate the unit. The highest unit of the Papoose Lake Member (Cbpc) comprises nearly 300 m of laminated to thick-bedded limestone and dolomite, with nodular chert common in the uppermost part of the unit. The contact with the overlying Banded Mountain Member is unconformable and is placed at an abrupt lithologic contact from a red-weathering siltstone to massively bedded, ledge-forming, dark-gray, limestone (Burchfiel, 1964).

The Banded Mountain Member (Cbb) is approximately 730 m in total thickness. The lowest unit (Cbba) is 90 m thick, the lower third of which is slope-forming, orange-weathered silty limestone. The upper third is cliff-forming, medium to dark gray limestone (Sargent and Stewart, 1971). It grades upward from thin, undulatory beds to massively bedded. The middle unit (Cbbb) is 450 m thick in the Striped Hills. It is dominated by alternating light and dark-gray beds, 2-10 feet thick (Sargent et al., 1970). The beds are commonly thin to laminated with varying amounts of chert throughout. The highest unit (Cbbc), 150 m, is light to medium gray limestone and dolomite. The lower half of the unit contains thick beds, whereas the upper half is laminated to thin bedded. This unit is probably detached from the Cbbb.

The overlying Dunderberg Shale is mainly fossiliferous, fissile, brown shale ranging from 15 to 100 m thick (Sargent et al., 1970). The predominant rock type is very thin bedded brown shale. Ledge forming, thick-bedded, limestones become more abundant upward and are interbedded with silty limestones and shales. This upper unit grades into the overlying Nopah Formation (Burchfiel, 1964). The weak shale commonly accommodates detachment of overlying Nopah Formation and where it has been obliterated Bonanza King Formation directly underlies Nopah Formation.

The Nopah Formation has been subdivided into two units, the Halfpint and Smokey Members (Sargent and Stewart, 1971). The basal 25 m of the unit is marked by coarse-grained, ledge-forming, limestone with sporadic orange, silty, interbeds. The remaining section of the Halfpint member, 100 m, is massively bedded, predominantly light to medium gray, dolomite with two distinctive white bands close to the base. The Smoky member, 300 m (Sargent and Stewart, 1971), is characterized by its light to dark gray, thin to thick bedded dolomite with minor amounts of nodular chert that give the unit a distinctive banded appearance (Burchfiel, 1964). Bedding becomes thinner upward with orange silty interbeds becoming more common. The Nopah is as thick as 425 m, although that thickness is known only at a single locality in the southeastern Specter Range (Burchfiel, 1964). In general the formation is strongly brecciated as described below and clearly has been strongly thinned along its contact with the Dunderberg during stratigraphic sliding.

The Nopah grades into the Ordovician Pogonip Group that is divided into three formations, which in places are difficult to differentiate, except at the type section they were defined by. The Goodwin Formation, 300 m. thick at it's type location at Goodwin Canyon near Eureka Nevada (Merriam, 1963) but is only about 240 m in the Striped Hills (Sargent et al., 1970) and often thinner than that or missing in the Specter Range. It is predominantly limestone with minor thin-bedded dolomite at its base, defining the lower contact. The formation is light to medium gray, with local mottling. Chert is present throughout the formation but typically varies from nodules at the base to laminar beds towards the top of the unit (Burchfiel, 1964). The Ninemile Formation, approximately 100 m thick in the Striped Hills, is light-gray to grayish-red laminated to thin bedded limestone, with interbedded silty and shaley horizons. The contact with the overlying Antelope Valley Formation is placed at the top of an orange-red, slope-forming unit below massively bedded, cliff-forming, limestone. Thicknesses of the Ninemile Formation vary greatly even in the vicinity of Ninemile Canyon where the unit is 150 m thick but only 60 m thick at Antelope Valley. Previous workers (Merriam, 1963) have cited tectonic thinning along silty and shaly horizons for the inconsistent thicknesses.

The Antelope Valley Formation is approximately 370 m thick (Sargent et al., 1970) in the Striped Hills and one locality in the Specter Range, where it is overturned south of the SRT. These thicknesses are common to those cited at Antelope Valley as well. The formation is easily distinguished from a distance by its medium-grayish-blue color. Well-defined beds, a few centimeters to a few meters thick are common in the lower half of the unit with scattered orange weathered, silty interbeds. The lowest 100 m contains abundant nodular and laminar chert. The middle third contains abundant fossils in the thick-bedded limestone units

(Sargent and Stewart, 1971). Fossils, include coiled and straight cephalopods, gastropods and sponges (Fig. 9). The thickness of the Antelope Valley in the southeastern Specter Range is approximately half the thickness it is in the Striped Hills. This is probably due to the top 100 m of thin-bedded, gray limestone with orange-weathering silty limestone interbeds that allow the overlying Eureka Quartzite to detach. In some places however this transition 100 m is missing and clean, white, vitreous quartzite rests directly on top of thick-bedded limestone of Antelope Valley Formation. The missing transition may indicate a facies change within the Eureka Quartzite or the effects of sliding along the detachment between the two units.

Figure 9. Fossileferous limestone in the middle 400 feet of the Antelope Valley Formation.

The Eureka Quartzite is about 140 m (Sargent and Stewart, 1971) in the Specter Range just south of the hill 4850 adjacent to the SRT. This thickness is concordant with an isopach map from (Ketner, 1986), illustrating the southeastward thinning. A complete section should have sandy dolomite at the base and top. The quartzitic dolomite becomes more quartzite rich upward in the section. The quartzite is commonly intensely fractured and may be brecciated. It is composed of white, vitreous quartzite, which may be friable where weathered, with little variation in grain size. Bedding is rather inconspicuous unless bedding planes are emphasized by weathering. At some localities the unit becomes more abundant in dolomite upward and grades into the overlying Ely Springs. On the other hand, there is often an abrupt transition from quartzite to the dark gray Ely Springs above. Complete sections are rare due to detachment horizons at the top and bottom of the unit and generally approximately 90 m of Eureka are preserved (Plate 1; A-A', B-B').

The contact of the Eureka Quartzite and Ely Springs Dolomite is easily mapped as it is marked by an abrupt transition from white quartzite or sandy dolomite to dark-gray to black massively bedded dolomite. The thickest exposure of the Ely Springs dolomite, which crops out just south of hill 4850, is approximately 140 m thick. In general, like the Eureka, the formation is only 90 m thick south of the SRT. The lower part of the unit is commonly heavily brecciated near the contact with the Eureka Quartzite. Most of the formation is dark-gray, thick-bedded dolomite with abundant fossils and sparse chert. The upper 20 m of the unit is typically is light gray and contrasts with the overlying dark Silurian dolomite (Burchfiel, 1964). From a distance there is a sharp transition from the dark-gray to black, Ely Springs Dolomite and this light gray Upper Silurian peak forming unit (Fig. 10).

Figure 10. Photo of the abrupt transition from the dark Ely Springs Dolomite to light gray undifferentiated Silurian rocks. Orange-gray Eureka Quartzite in the foreground.

(Burchfiel, 1964) mapped Silurian rocks in Specter Range as undifferentiated because brecciation obscures bedding planes. Subsequently (Sargent and Stewart, 1971) subdivided the Silurian rocks based upon the section located on hill 4850 where they recognize lower, middle and upper units. The lower unit is only 20 m thick, dark-gray in the lower half and light-to medium gray in the upper half. Laminations and nodules of chert at the base become sparser upwards. The most distinctive features are recrystallized coral heads and columnals which may be as large as 1 foot in diameter. The middle unit, 170 m thick, is a light- to dark-gray dolomite that is laminated to thin-bedded. The basal 15 m is quartz siltstone with common chert layers. The upper part is a yellowish gray dolomite. Fossils are abundant throughout the unit. The upper unit is 275 m thick in the type section south of hill 4850. The cliff-forming unit is massive in the lower half and thick-bedded in the upper half. Locally, laminae are defined by medium- to light-gray carbonate bands.

The subdivided Silurian stratigraphic section is unrecognizable at most Specter Range localities because of strong brecciation; therefore the undifferentiated section, 670 m thick, described by (Burchfiel, 1964) will be discussed. The lower part of the Burchfiel section is correlated with that south of hill 4850 previously described. The lower unit as a whole is generally identified by alternating light- to dark-gray bands of dolomite. Three bands are found in the type section and two bands in a section farther south of the SRT. The upper unit contains beds of light-gray and gray dolomite commonly between less than a meter to three meters thick. Generally the thick bedded units are composed of medium- to coarse- grained dolomite, whereas thin-bedded units are fine- to medium- grained dolomite. Most of this unit however, is severely brecciated and bedding planes are obscured. Steeply dipping zones of fine grained cemented breccia within zones of coarser grained breccia or cohesively bedded rocks are exclusive to this unit.

The Early and Middle Devonian Nevada Formation is the next Paleozoic unit exposed in the Specter Range Quadrangle and is also probably detached. Its age is constrained by corals found in the basal unit and brachiopods found in the upper 50 m. The formation comprises lower and upper members. The lower member, 140 m, consists of olive-gray medium bedded dolomite at the base and an upper unit of medium to coarse grained quartzite with minor dolomitic, silty interbeds. The interbeds become more abundant upwards and grade into the upper member that is approximately 370 m thick (Burchfiel, 1964). It has a banded appearance defined by dark and light-gray dolomite..

More than 300 m of the Devil's Gate Limestone crops out in Specter Range. However, the stratigraphy and actual thickness of this unit can not be well described due to the fact that it is cut by several faults. (Johnson and and Hibbard, 1957) measured a complete section 400 m thick 5 miles east of the Specter Range suggesting at least 100 m are not exposed in the Specter Range. Furthermore (Johnson and and Hibbard, 1957) mapped 100 m of white vitreous quartzite at the top of the formation on the Nevada Test Site. Quartzite associated with the Devils Gate Limestone in the Specter Range is only one third that thickness. The base of the unit is medium-bedded, light gray dolomite interbedded with the thick-bedded limestone typical of most of the formation (Burchfiel, 1964). The most common rock type in the formation is thick-bedded, dark-gray to blue-gray limestone.

3.1.3 Tertiary

Sedimentary and volcanic beds of Tertiary age directly overlie Paleozoic strata in the Specter Range. Higher Paleozoic formations and Mesozoic units present in the Spring Mountains to the south do not crop out in the Specter Range quadrangle. The Tertiary units are generally thinner versions of the formations associated with the Southwestern Nevada Volcanic Field that are well studied in the Yucca Mountain area (Laczniak et al., 2001). The Oligocene Horse Spring Formation is the oldest Tertiary unit is the quadrangle. There are several different members of this formation (Page et al., 2005); a conglomerate and lacustrine derived member are present. In the near by Las Vegas Range a basalt is found interbedded within the conglomerate member. Basalt dates yield Miocene K-Ar ages (Page et al., 2005). However biotite in bedded tuff in the Mercury Quadrangle yielded Oligocene ages (Sargent and Stewart, 1971). Base upon proximity to the field area the assumption is made that the Oligocene age unit is probably the one mapped in the Specter Range quadrangle. In the Specter Range the Horse Spring Formation is down faulted against the Bonanza King Formation along normal faults and a complete section does not exist.

4.0 Previous Work

There are several structures that have been previously identified through out the study area, some of which serve as boundaries for different structural domains. Several Paleozoic and Mesozoic Orogenies (i.e. Antler, Sonoma, Sevier and Laramide) produced east vergent thrust systems and related north-south anticlines. Recogonition of these structures is often difficult as several episodes of Tertiary faulting have over printed their previous geometries.

The middle Paleozoic Antler orogeny is characterized by several east vergent thrust faults and associated north-south trending fold hinges. One example is the Roberts Mountain thrust that emplaces Ordovician through Devonian miogeoclinal rocks onto Paleozoic shelf rocks (Poole, 1974; Stewart and Poole, 1974). As the Antler Orogeny progressed exotic terranes were accreted, resulting in the eastward migration of a foreland basin, forebulge and backbulge structure (Morrow and Sandberg, 2008). The Antler forebulge uplifted shallow marine carbonate rocks to subareial conditions and erosion ensued, leading to development of a regional unconformity.

The Sevier-Laramide orogeny, late Mesozoic to early Tertiary (Fleck, 1970), produces another east vergent thrust system with associated north-south fold hinges (Poole et al., 1992). Early Sevier deformation is characterized by the emplacement of a magmatic arc and associated foreland fold-and-thrust belts between 120-80 Ma (Livaccari, 1991). As the convergence rate of the Farallon Plate subducting beneath western North America increased between 105-100 Ma magmatism progressed eastward (Engebreston et al., 1985). Therefore between 120-85 Ma the Sevier fold-and-thrust belt experienced its highest degree of deformation. Post 80 Ma deformation prograded eastward into the Laramide Rocky Mountains. Deformation associated with the Laramide orogeny persisted from the late Cretaceous to the late Oligocene in the south-central Cordillera (Dickinson et al., 1988). The trace of the orogenic front has been offset and bent due to fault drag alone the LVVSZ (Fig. 11).

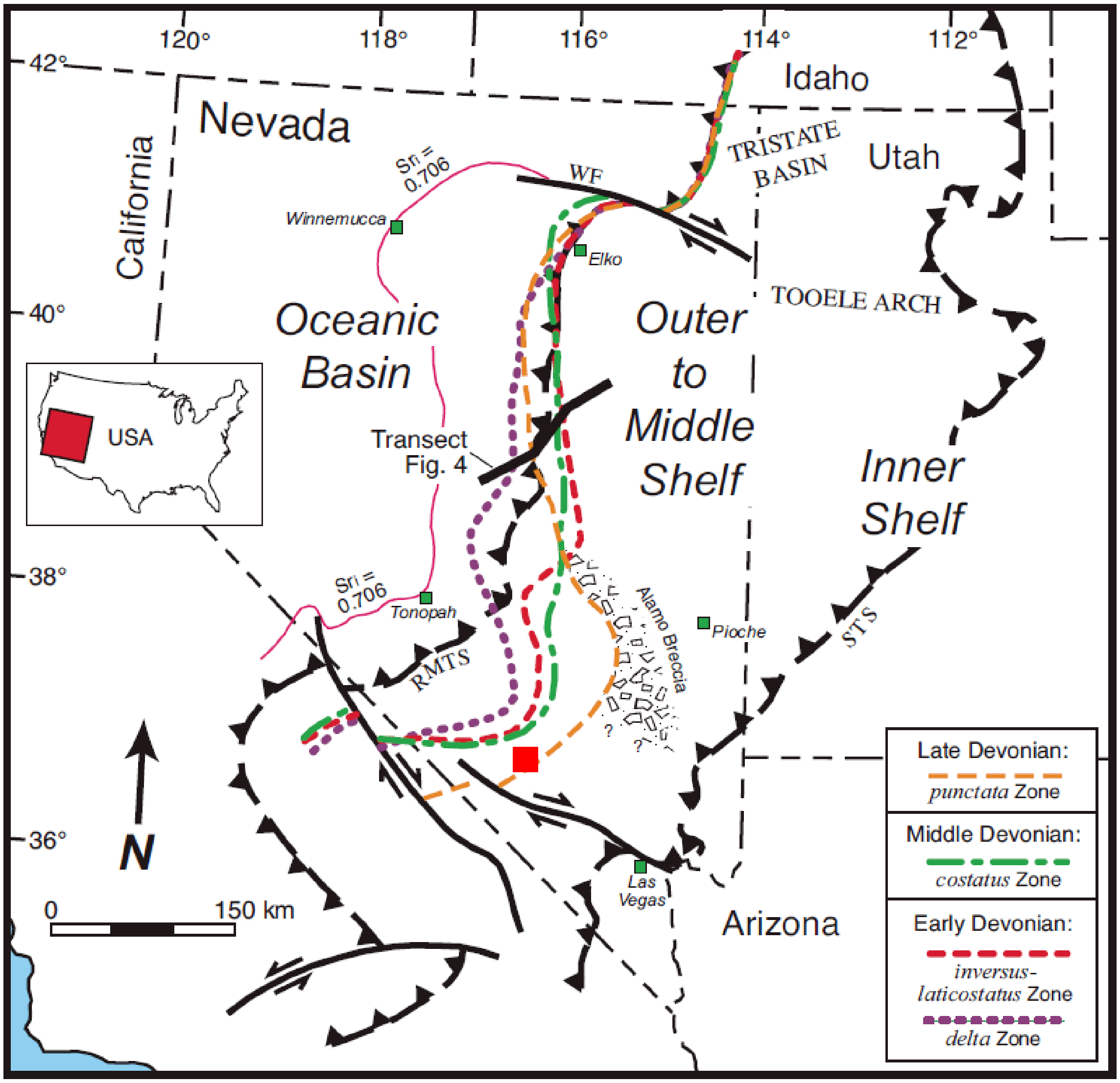
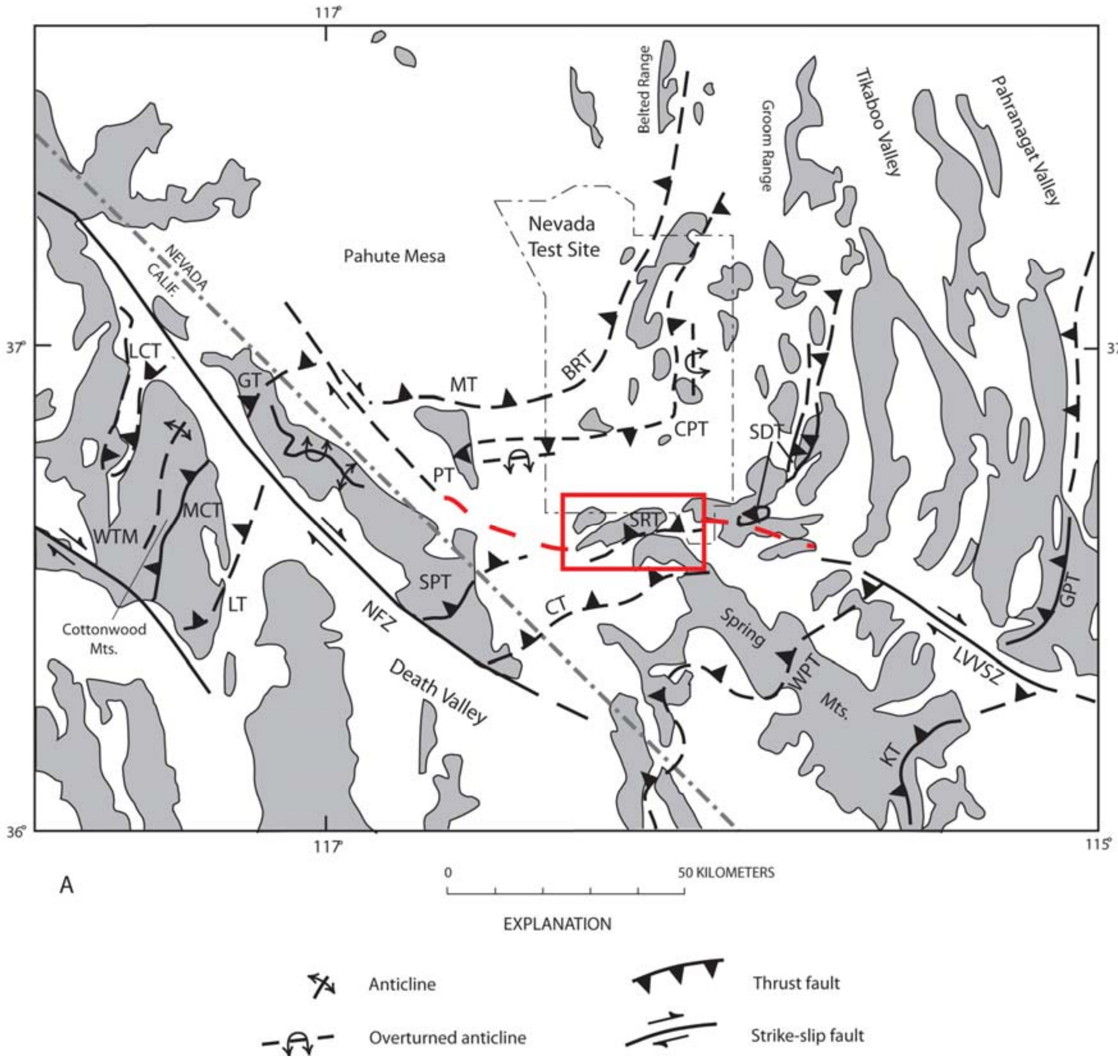


Figure 11. The evolution of the carbonate shelf along the margin of western North America. Figure from (Morrow and Sandberg, 2008), Red box denotes location of field area (Strike-slip fault which crossing field area is LVVSZ). STS-Sevier Thrust system, RMTS-Roberts Mountain Thrust system, WF-Wells Fault. The field location is denoted by the red box at the terminus of the LVVSZ.

4.1 Structures

There are several key structures which influence the current position and orientation of the Specter Range and Striped Hills. They are the LVVSZ, Walker Lane domain, the SRT and the RVF. Several authors (Albers, 1967; Burchfiel, 1965) have suggested the linkage of the LVVSZ and the Walker Lane domain at depth beneath Amargosa Valley (Fig. 12). Three sets of high-angle, Miocene faults have also been identified which displace segments of the hanging wall and footwall of the SRT.



Key

LVVSZ-Las Vegas Valley shear zone, SRT-Specter Range Thrust, NFZ-Northern Furnace Creek Fault zone WPT-Wheeler Pass Thrust, KT-Keystone Thurst, GPT-Glass Peak Thrust, CT-Clery Thrust, MT-Meiklejohn Thrust, BRT-Belted Range Thrust, LT-Lemoigne Thrust, SPT-Shwaub Peak Thrust, PT-Panama Thrust, MCT-Marble Canyon Thrust, WTM-Whitetop Mountain Thrust, SDT-Spotted Range Thrust, LCT-Last Chance Thrust, GT-Grapevine Thrust, WL-Walker Lane extensional domain.

Figure 12. Right-lateral offset along the LVVSZ as evidenced by fault drag along the shear zone and offset of older thrusts in the Spring Mountains and Sheep Range. The red box illustrates this thesis study area. Red dashed line denotes the possible link of the LVVSZ and the Walker Lane. Figure modified from (Cole and Cashman, 1999)

4.1.1 Las Vegas Valley Shear Zone

The LVVSZ is a dextral shear zone whose trace roughly mimics the trend of Hwy 95 between Lake Mead and Mercury Valley (Fig. 12**)**. It was active during the middle Miocene between 15-10 Ma (Bohannon, 1984) and accommodates extension between the Spring Mountains and the ranges north of Hwy. 95 between Las Vegas and Mercury, Nevada (Cole and and Cashman, 1999). The Ranges north of Hwy. 95 have experienced nearly 40 km of westward extension via the Sheep Range detachment system (Guth, 1981). The LVVSZ isolates the Spring Mountains to the south from such detachments. Between 25 and 40 miles of offset has been documented along the transect (Table 1) between Lake Mead and Mercury (Burchfiel, 1965; Longwell, 1960; Stewart, 1967). Offset and fault drag is apparent by right-lateral restoration of the several Mesozoic thrust in the Spring Mountains to the south and the Sheep and Belted Ranges to the north. Offset of Precambrian to Silurian isopach lines and sedimentary facies also suggests similar displacement values.

Table 1. Comparison of supporting evidence for offset along the LVVSZ. From (Stewart et al., 1968)

Right-Lateral Offset Documented Along LVVSZ

Map Evidence	Distance (Miles)	Author
Offset thrusts	≥ 25	Longwell, 1960
Offset thrusts	≥ 27	Burchfiel, 1965
Offset isopach lines and distribution of Eureka Quartzite	25-40	Ross and Longwell, 1964
Offset isopach lines of Precambrian to Lower Cambrian formations	30	Stewart, 1967
Offset in Devonian isopachs and facies	30	Poole et al., 1967
Offset of southeastern limit of Silurian aged rocks	35	Stewart et al., 1968

Near Indian Springs, NV the LVVSZ bends left and right-lateral offset is no longer apparent. Bedding adjacent to the SRT rotates from northeasterly to E-W. (Albers, 1967) suggests a clockwise orofexural bend in the Spotted Range near Mercury Nevada, as offset demonstrated along Las Vegas Valley is no longer traceable. The oroflex itself, however, wouldn't accommodate all the documented offset (~30 miles); therefore we suggest significant detachments in the vicinity of the Specter Range. Furthermore the SRT probably also accommodates a significant amount of the offset along the LVVSZ. Approximately 60 miles west begins the extensional Walker Lane Domain, likely active while there was movement along the LVVSZ (Albers, 1967; Stewart, 1988) and possibly links at depth beneath Amargosa Valley (Burchfiel, 1965).

If older Mesozoic thrusts in the Spring Mountains were reactived and their movement was synchronous with strike-slip motion along the LVVSZ (Longwell, 1960) the ESE maximum principle stress direction associated with thrusting does not satisfy stress criteria associated with strike-slip faulting. If thrusting and transcurrent motion occurred at different depths, independent of one another contemporaneous deformation is possible. This idea may be applied to the Specter Range where bending at bedrock depth is transferred to stratigraphically higher units, where stress exploits weak layers and develop detachment horizons along horizontal bedding planes (Burchfiel, 1965). Field evidence has indicated several detachments horizons exist. From lowest to highest they are the Wood Canyon Formation, the Zabriskie Quartzite, the lower Bonanza King (Cbpa), middle Bonanza King (Cbpb/Cbpc) and (Cbba), upper Bonanza King (Cbbc), Dunderberg Shale (Nopah), Antelope Valley/Ninemile Formation, the Eureka Quartzite/Ely Springs Dolomite, undifferentiated Silurian rocks, and the Nevada Formation. Intra-unit detaching is also evident by brecciation which formed along bedding planes and a commonly alternating pattern of cohesively bedded layers and brecciated material.

4.1.2 Walker Lane Domain

The Walker Lane Domain (Fig. 13**)** is northwest trending, right-lateral, extensional zone about 100 km wide and 1000 km long. It is defined as the boundary between northeast trending ridges to the north and northwest trending ridges to the south. (Albers, 1967) recognized a zone about 80 km wide where the two opposing trending ranges converge. He proposes this convergence gives two ranges between the LVVSZ and the Walker Lane their arcuate shape, one of which is the Specter Range. Assuming its dextral shear sense and linkage with the LVVSZ, the Walker Lane Belt may be interpreted as a transtensional domain along a right-lateral, strike-slip fault. Applying the rationale of (Burchfiel, 1965) it is possible that strike-slip motion does continue to occur at bedrock depths, evidence of which is covered by the Amargosa Desert and the Southwestern Nevada Volcanic Field, then re-emerges at the Walker Lane deformational Belt (Albers, 1967; Stewart, 1988).

Faulting associated with the Walker Lane domain probably began in the late Oligocene and partially reorients older extended terranes to the east (Ekren and Byers, 1984) and separates them from the Sierra Nevada to the west. Evolution of the Walker Lane is described by ENE, left-lateral faults developing within a westward widening transtensional zone where maximum principle stress rotates clockwise from north-south to NNE-SSW (Stewart, 1988; Wright, 1976) (Fig. 13).

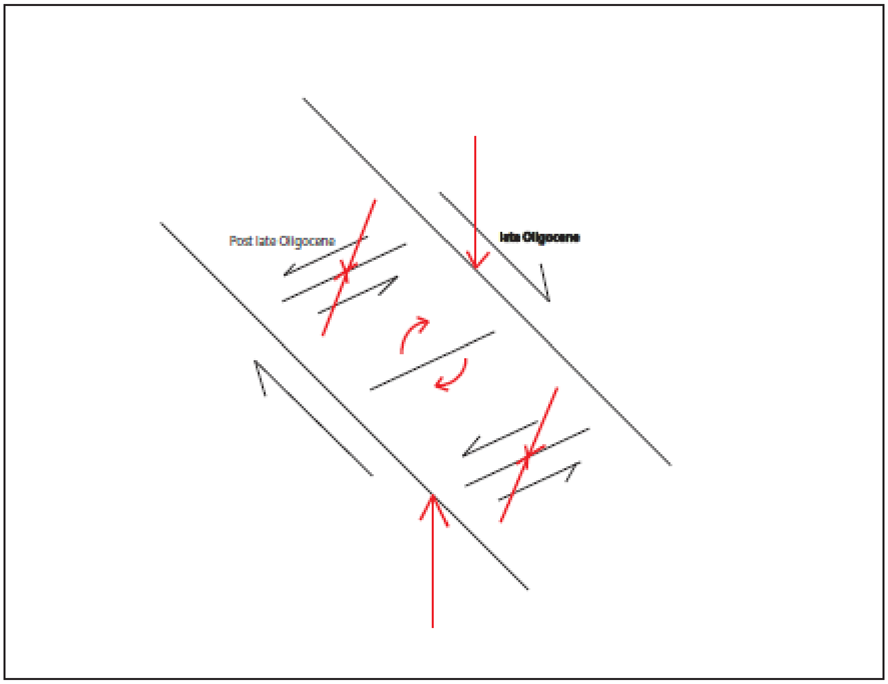


Figure 13. Figure showing the clockwise rotation of maximum principle stress from north-south in the late Oligocene to NNE post late Oligocene. Maximum principle stress directions are indicated by red arrows. Figure produced from (Albers, 1967).

4.1.3 Specter Range Thrust

The SRT, active between 15 and 10 Ma (Bohannon, 1984), is defined (Burchfiel, 1965; Sargent and Stewart, 1971) as a Tertiary contractional structure in response to the LVVSZ. At the contact the SRT emplaces of the Wood Canyon Formation on top of the Pogonip and Nopah Formations. The Wood Canyon Formation forms a powdery gouge at the contact and has been thinned by approximately 600 m (Fig. 14). There is over 1800 m of stratigraphic separation in total at the contact, as the Carrara and Bonanza King Formations are cut out (Plate 1; A-A'). It is likely that the SRT is a shallow angle fault as postulated by (Sargent and Stewart, 1971) and that detached units adjacent to it are related to thrust motion along it.

Prior to SRT motion, the region was dominated by older north-south fold hinges (Abolins, 1999), some of which are still evident approximately 3 km south of the present day contact. Bedding just south of the SRT has formed E-W fold hinges likely due to Tertiary transpression along the LVVSZ.

Figure 14. Photo of gouge from Nopah Formation in the footwall of the SRT. This photo is located at UTM zone 11N 574504 4055211.

4.1.4 Rock Valley Fault

The RVF is an ENE striking structure. On average it is 5 km wide and 32 km long, extending from Frenchmen Flat and bending south towards Amargosa Valley at its western most extent. It's mapped as an inferred, left-lateral, strike-slip fault along which the Striped Hills have been overturned (Sargent et al., 1970; Sargent and Stewart, 1971).

The RVF zone separates rocks of the southwestern Nevada volcanic field and the Striped Hills to the north and Paleozoic carbonates of the Specter Range to the south. (O'Leary, 2000) interprets the RVF zone as seismically active zone associated with the Walker Lane domain which localizes extensional strain between the Spring Mountains and the southwestern Nevada volcanic field. It also doesn't seem to accommodate detachment faulting recognized throughout most of the Specter Range. Splays of the main fault cut and displace detachments in the northern Specter Range. Offset along the splay which separates the Striped Hills and the Skeleton Hills to the south has been measured at 1.4 km. Like in the segments of the Walker Lane to the north, reorientation of older structures appears to occur in the area of Rock Valley as well (Stewart, 1988). The first episode of normal faulting in the area predates the late Oligocene Walker Lane ages and was probably subsequently rotated clockwise (Fig. 13). Another evolution of the RVF may be related to the three episodes of Cenozoic extension throughout the Basin and Range province. Both Eocene and Miocene stress regimes produced left-lateral strike-slip faults whose trends are in accordance with the RVF. Furthermore maximum principal tension direction during the Oligocene was parallel to the left-lateral faults which developed during the Eocene. Therefore it is possible that the RVF was reactivated several times since its inception.

The eastern termination of the fault is covered by alluvium in Frenchman Flat but has been interpreted to truncate along the northeast striking, right-lateral, Yucca Fault along with the Cane Spring and Mine Mountain faults (Carr, 1984), The western termination is likely abuts against the Gravity fault (Winograd and Thordarson, 1975), inferred to extend from the west side of Little Skull Mountain to the west end of the Skeleton Hills.

As previously mentioned the north-south trending faults which form the basins between the SRT and RVF are splays of the RVF (Fig. 15). The fault pictured below is probably one of those splays. It is located at on the eastern side of range in the northern Specter Range adjacent to a basin formed by a splay of the RVF. The fault orientation is NNE-SSW consistent with Oligocene ages and left lateral strike-slip motion (Fig. 16). It was also probably reactivated during mid-Miocene extension as a normal fault.

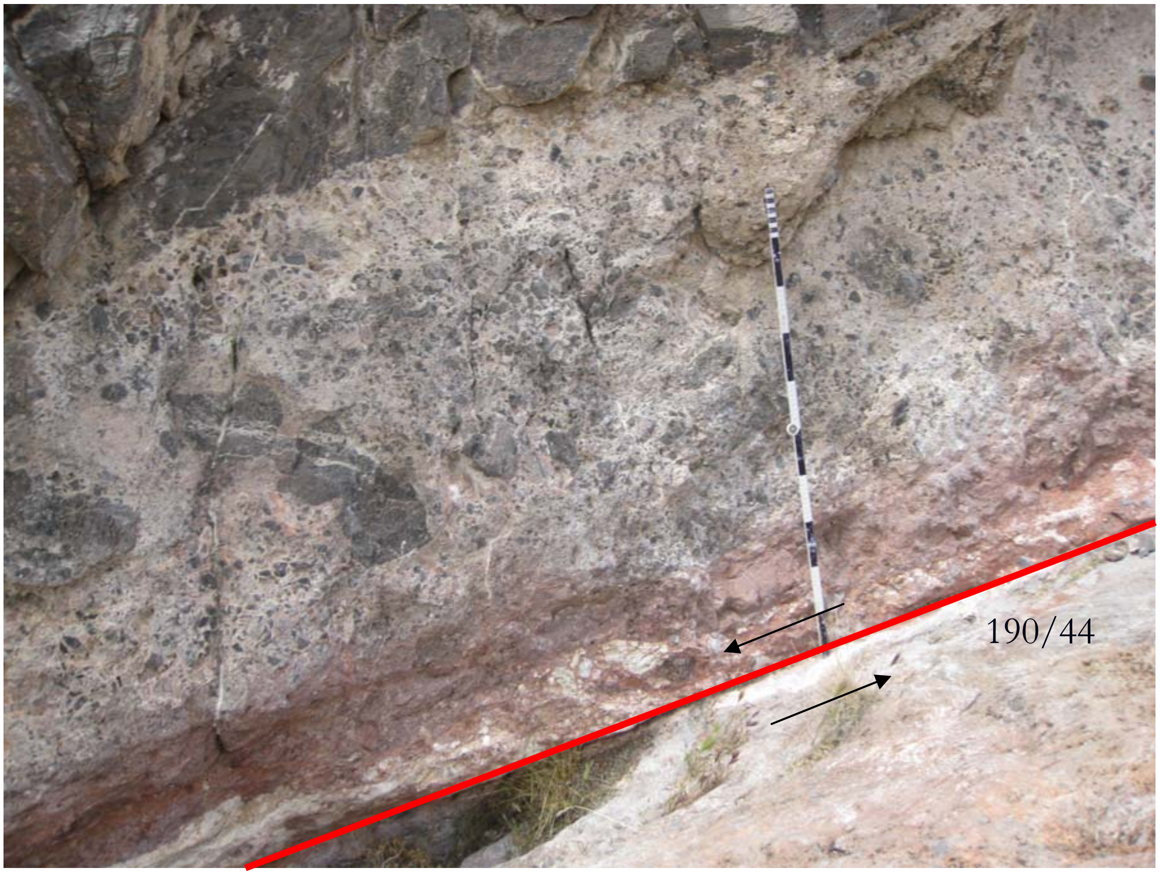


Figure 15. Fault measured in the northern Specter Range, possibly associated with the RVF. This is a fault in the lower Bonanza King Formation. Fault zone is over one meter wide with asymmetric margins and pebble to boulder sized clasts. This photo is located at 11 N 565071 4054547 (UTM_NAD 1927)

4.1.5 Faults and Fractures

There are three main Cenozoic extensional events that have overprinted Paleozoic and Mesozoic structures in the study area (Fig 16). Therefore recognizing these older structures and understanding their pre-Cenozoic stratigraphic relationships is quite challenging. Eocene extension lasted from 55-48 Ma with a principal transport direction of 290º, therefore normal faults were oriented NNE-SSW and complimentary strike-slip faults bisected the angle between the normal faults and the direction of least principal stress. A second episode of extension related to metamorphic core complexes occurred from the Oligocene to early Miocene (33-20 Ma), in which the direction of least principal stress rotated to 240º so that normal faults developed with a NW-SE orientation. The left-lateral set of complimentary strike-slip faults developed roughly parallel to pre-existing normal faults associated with Eocene extension. The most recent extensional episode of basin and range faulting began in the mid-Miocene and is still active today. The present day stress-regime of the basin and range roughly mimics Eocene extension, with the least principal stress direction changing by only 005º. Once again older structures (NW-SE normal faults) were probably reactivated during the mid-Miocene as right-lateral strike-slip faults. Likewise, Eocene left-lateral faults were probably reactivated with the same sense of motion at the onset of the current Basin and Range extensional regime (Burchfiel, 1965).

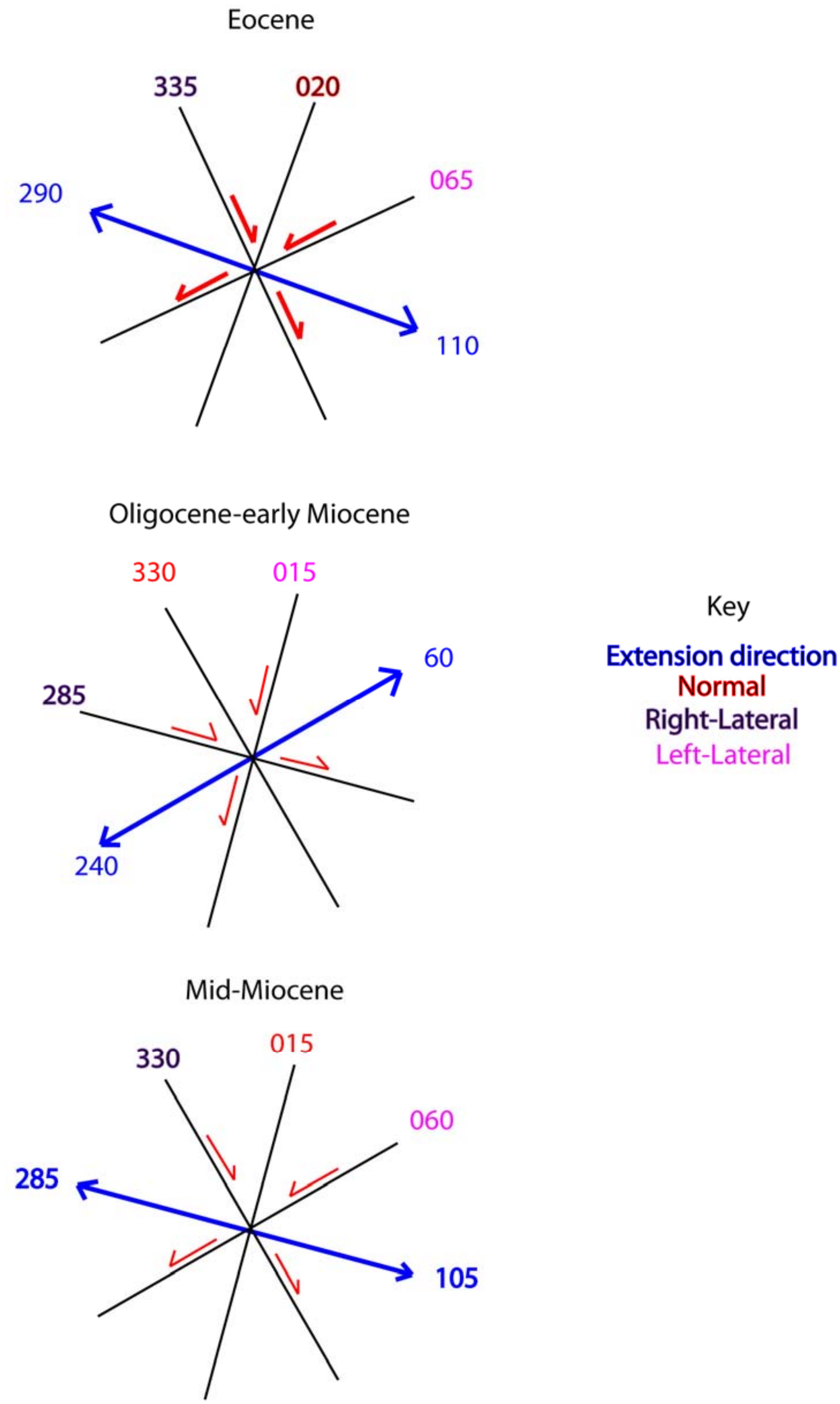
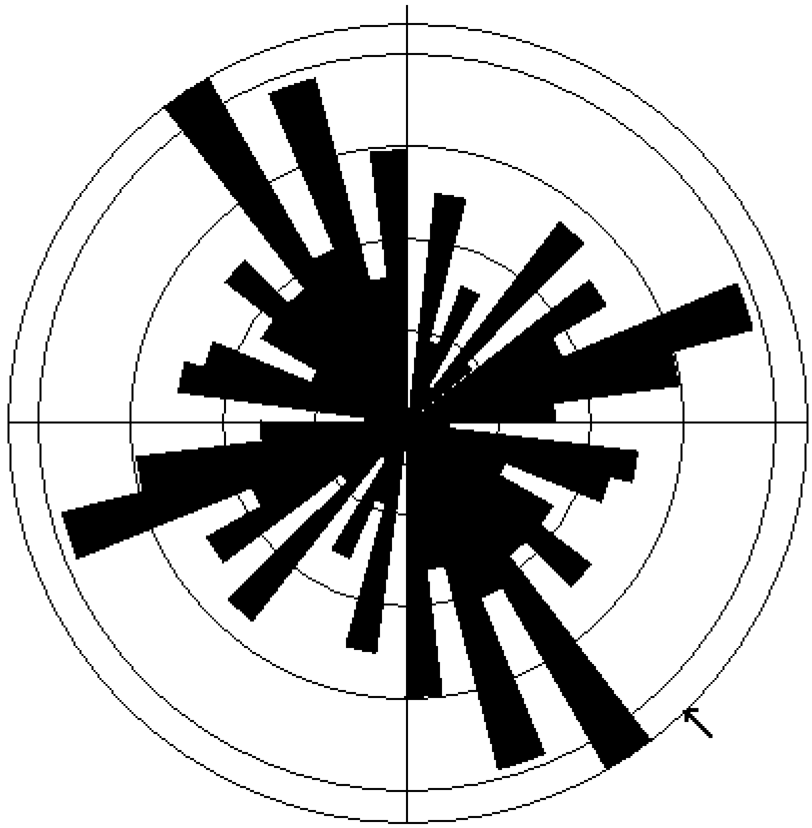


Figure 16. Illustrations of three principal extensional periods during the Cenozoic with normal faults labeled 90 degrees to the extension direction and complimentary shears which bisect the angle between the normal fault and the stress direction.

Fracture data collected through out the entire field area (Fig. 17) appears to be representative of these three episodes of Cenozoic extension. The average strike of fractures is 316º and the secondary set appears to be directed at approximately 240º. During the three episodes of Cenozoic extension the NW-SE set of faults developed with left-lateral, normal and left-lateral movement from oldest to youngest. Therefore the NW-SE set of faults is dominant on the rose diagram. The secondary set of faults (240º) was active as right-lateral faults during the Eocene and mid-Miocene (Fig. 16). The north-south set of faults probably represents the regional north-south faults which control most of the half-graben topography throughout the Basin and Range. At depth the faults shallow into detachments like the Sheep Range detachment system (Lister and Davis, 1989). The two sets of strike-slip faults are probably conjugate shears (Wright, 1976).



Axial (non-polar) data
No. of Data = 219, Sector angle = 8°, Scale: tick interval = 2% [4.4 data]
Maximum = 8.7% [19 data], Mean Resultant dir'n = 136-316

Figure 17. Rose diagram of all fractures measured in the study area.

4.1.6 Folds

There are a series of north plunging fold hinges which have been identified (Abolins, 1999) and likely formed during Paleozoic and Mesozoic orogenic events (i.e. Antler and Sevier Orogenies). In the southeastern corner of the Specter Range (Burchfiel, 1965) recognized a series of northeast plunging open folds. This relationship is suggested by the distribution of map units and is further supported by a stereographic projection of bedding in the area. An equal area plot reveals the beta axis trend/plunge measures 025/17 (Fig. 18). The map pictured below suggests a series of northeast plunging anticlines and synclines. The Wood Canyon Formation defines the northern most hinge and infers detachment along its fold hinge. The Nopah Formation also defines an anticline and is detached on to the Bonaza King Formation. Lastly, the Antelope Valley Formation defines the hinge of a syncline and is detached from the Nopah Formation. The fold hinges in the Paleozoic carbonates are likely detachment related. As the units detach towards the south they exploit the previous topographic features formed during the Paleozoic.

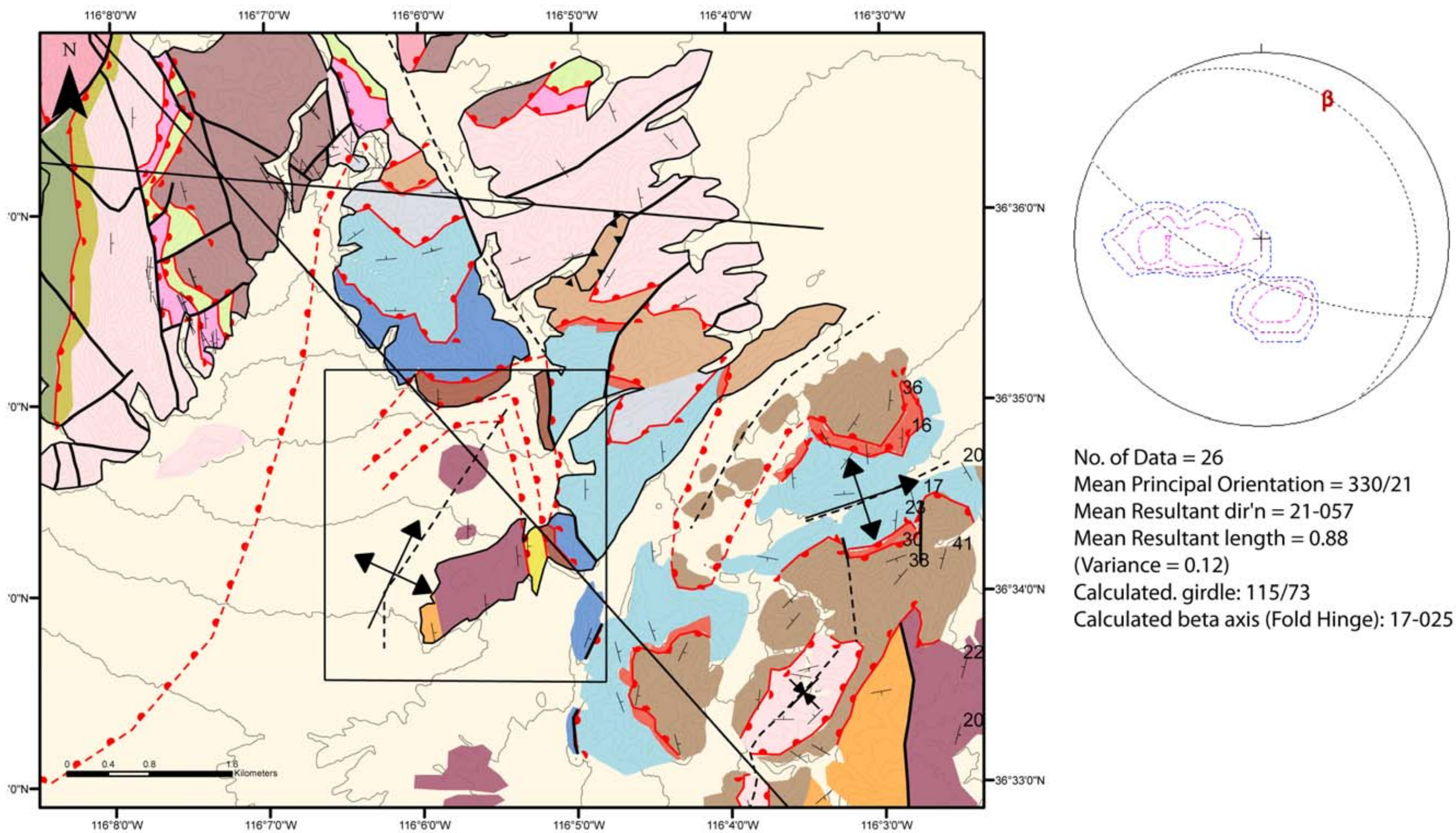


Figure 18. Bedding data in the southern Specter Range/Northern Spring Mountains illustrates a NNE, shallowly plunging, open fold. The black box on the map encompasses bedding data used for the stereonet to the right. Map was modified from (Burchfiel, 1965: Piaschyk, 2007). For lithologic and structural explanation see plate 1.

An open, north-plunging, anticline is also interpreted in the southern Specter Range. Bedding on the eastern limb dips east and west on the western limb. This structure is likely obscured by several north-south normal faults (Plate 1; B-B').

Just south of the SRT N-S structures are overprinted by E-W Tertiary structures (Fig 19). The Antelope Valley Formation defines a fold hinge, plunging shallowly westward. The Goodwin Limestone and Ninemile formations dip southward. Beds are overturned to the south in the Antelope Valley Formation and dip north and are slightly overturned. This E-W structure can be interpreted as a fault propagation fold in response to the SRT (Plate 1; A-A'). The Tertiary detachments described in detail in this manuscript probably accommodate a significant amount of shortening illustrated in the fault propagation fold associated with the SRT. Displacement along fault propagation folds commonly dissipate before they breach the surface and further shortening from the basal detachments are accommodated in the hinge of the fold at the terminus of the fault. This structure probably existed but has subsequently been eroded.

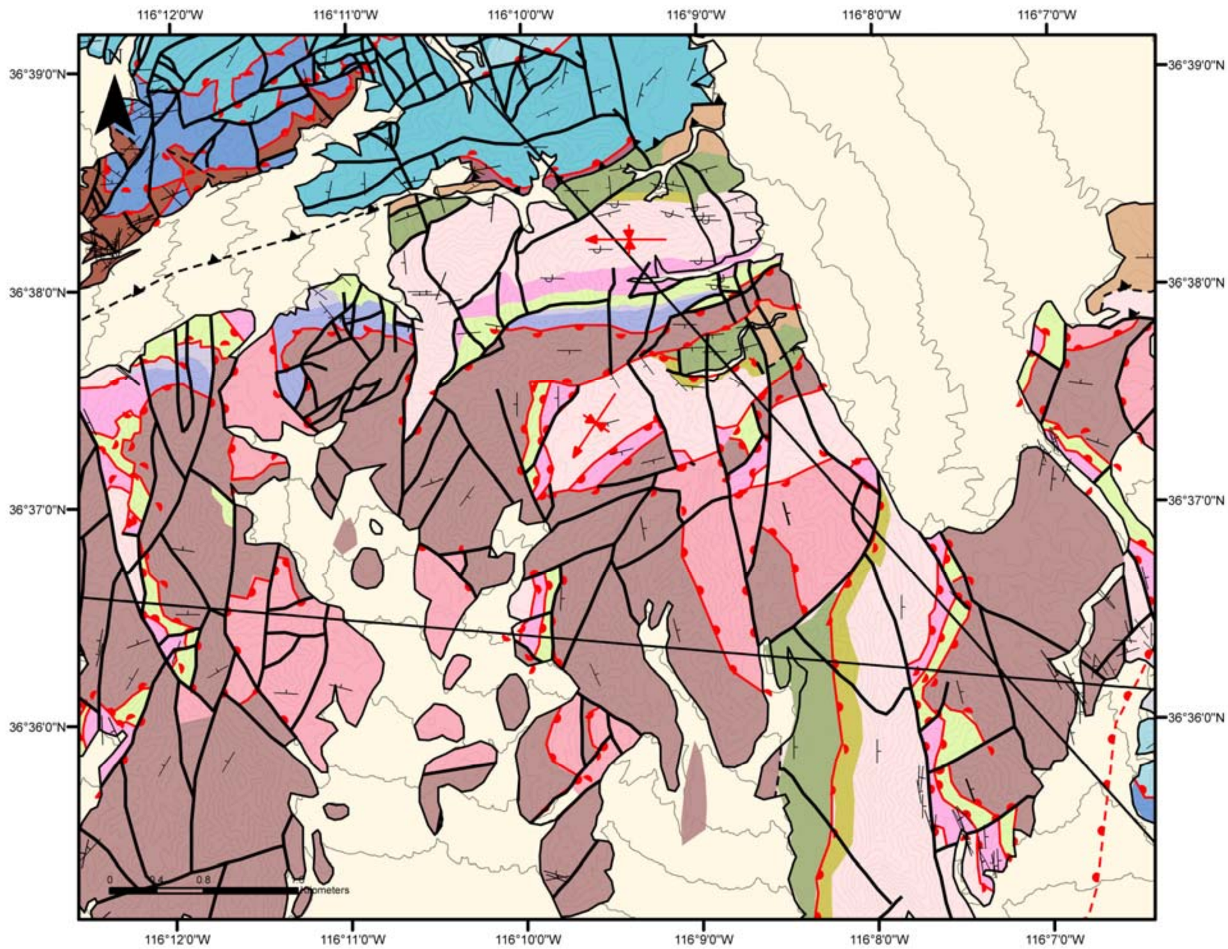


Figure 19. East-west fold hinges in middle Paleozoic carbonates just south of the SRT and south for approximately 3 km south. For lithologic and structural explanation see plate 1. Map modified from (Burchfiel, 1965, Piaschyk, 2007 and, Sargent and Stewart, 1971).

5.0 Results and Interpretations

Stratigraphy has been well defined by previous workers. We used this previous knowledge to modify the structural interpretation of the field area, primarily with stratigraphic detachments, which have been greatly thinned and brecciated large sections of the carbonate aquifer. Overall thinning in the field area was calculated to be 35%. The type section is based from thicknesses in the Striped Hills mapped by Sargent et al., (1970) and (Merriam, 1963) for the Pogonip section. The thinned thicknesses are measured in cross section A-A` (Plate 1) except right at the SRT contact where units are so severely thinned they are not representative of typical Specter Range stratigraphy. Detachment morphology throughout the field area appears to be greatly influenced by previous topography as they are often folded and mimic older Paleozoic and Mesozoic structures.

5.1 Detachments

Previous workers (Sargent et al., 1970; Sargent and Stewart, 1971) have documented several east-west trending normal faults, some of which, in our interpretation would be related to detachment faults. Detachments typically, initially localize along the boundary between crystalline basement and the cover rocks above or at depths close to the brittle ductile transition

(Lister et al., 1986). As these detachments are exhumed, however they begin to develop the brittle characteristics that have been well documented throughout the field area. Stratigraphic units have been thinned along detachments by nearly 3000 m (see Fig. 5). Slip along bedding planes is evidenced by brecciation. Brecciation may affect an entire carbonate formation, and horizons rich in silty beds may be greatly reduced in thickness or completely obliterated. Eleven different detachments (Table 2) are recognized in the study area. Some exist at every stratigraphic contact, while some units are detached in a certain locality but not the other.

Table 2. Best exposures of detachment locations listed in stratigraphic order. UTM are in NAD_1983.

Detachment Locations

Horizon	Zone	Easting	Northing
Wood Canyon	11 S	569283	4053947
Zabriskie	11 S	569190	4055191
Carrara	11 S	569121	4055790
Cbpa	11 S	567152	4052703
Cbpb/Cbpc	11 S	571684	4056170
Cbbc	11 S	580445	4050551
Dunderberg/Nopah	11 S	580354	4051041
Ninemile/Antelope Valley	11 S	577149	4049060
Eureka/Ely Springs	11 S	569726	4050802
Silurian rocks	11 S	571314	4051001
Nevada	11 S	574720	4050615

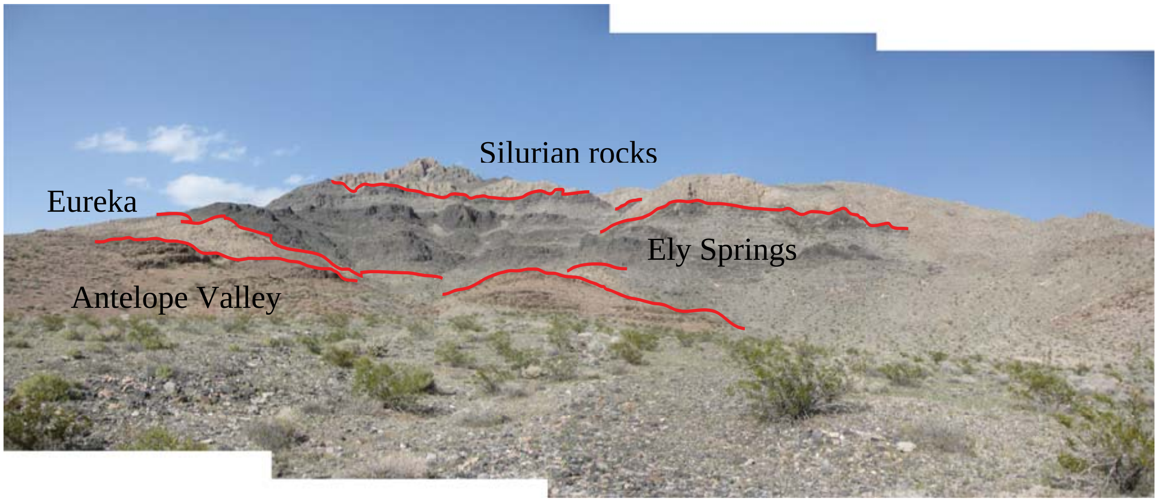


Figure 20. Ordovician to Silurian (lowest to highest) detachments in southern Specter Range. View is looking east. Photo taken from approximately UTM Zone 11 N 569026 4051643.

5.1.1 Wood Canyon

The Wood Canyon type section is 730 m (Burchfiel, 1964). The Wood Canyon found in the central Specter Range, however, is only about half that thickness, supporting the theory that it has also been thinned via detachment. The foliated Wood Canyon discussed earlier is interpreted to have developed as the Wood Canyon Formation detached over the Stirling Quartzite. Unlike the rest of the detached units, the stratigraphic contact resides at a deep enough depth that ductile structures are formed. Cleavage planes are defined by recystallized micaceous shale (Fig. 6). Further evidence is supported by the missing basal unit of dolomite in the study area, suggesting it has been thinned along a detachment horizon. Evidence from ductile and brittle structures suggests the formation resided at different structural levels (Fig. 21).

Figure 21. Photo of a small scale box fold in the Wood Canyon Formation and associated fracture which propogates through the hinge. Photo located at UTM Zone 11N 569379 4054016.

5.1.2 Zabriskie

The Zabriskie detachment is marked by scattered pieces of quartzite breccia that commonly mark the Zabriskie stratigraphic horizon, formerly more than 120 m. The Zabriskie Quartzite in the Specter Range however is commonly missing or less than 30 m. The sparsely preserved breccias are developed between the underlying Wood Canyon Formation and overlying Carrara (Fig 22). The silty units at the top of the Wood Canyon Formation likely, also aid in the detachment of this unit. A typical Zabriskie breccia, when found is similar to the figure below. Clasts sizes remain rather large, pebble to cobble in size are sub-angular to sub-rounded in shape, and cemented in a red quartzose matrix.

Figure 22. Zabriskie breccia cemented in a quartz rich martix. Clast range from pebble to cobble in size and often retain bedding.

5.1.3 Carrara

The Carrara Formation is especially susceptible detachment because of the abundance of silty and other fine-grained and/or thin-bedded rocks in the formation. The Carrara Formation is 500 m thick in the Striped Hills at the western margin of the study area. However, in the Specter Range there is only about 300 m (Sargent et al., 1970) indicating that about 200 m have been removed via detachment at the base and top of the formation.. Where exposed, the remaining Carrara Formation consists of beds striking approximately E-W. However, directly beneath the overlying Bonanza King Formation the uppermost beds are severely disrupted into large clasts commonly retaining beds cemented in a calcite-rich matrix (Fig. 7). In the western Specter Range the top of the Carrara Formation is so intensely brecciated that no bedding persists (Fig. 7). In the eastern Specter Range the same style of brittle deformation is not seen. In fact the Carrara adjacent to the SRT and in the hanging wall is well-bedded and locally foliated (Fig. 8).

5.1.4 Lower Bonanza King (Cbpa)

The basal unit of the Bonanza King Formation is commonly detached from the Carrara Formation. The detachment is defined by the change in bedding strike from one unit to the next (Fig. 23) and the intense brecciation that occurs along the contact. The relationship is demonstrated in the northern Specter Range where the general strike of the Carrara formation is west to northwest, whereas the bedding in the overlying Bonanza King is generally north striking, preserving the trend of pre-Tertiary structures (Fig. 23). At places the two formations imbricated along their contact (Fig. 23). At another locality the detachment changes its orientation so that it appears to be sliding along the strike of the underlying Carrara Formation and cuts shallowly down dip. The Carrara strikes E-W and dips 50º north, whereas the Bonanza King Formation measures 120/14 (Fig 23).

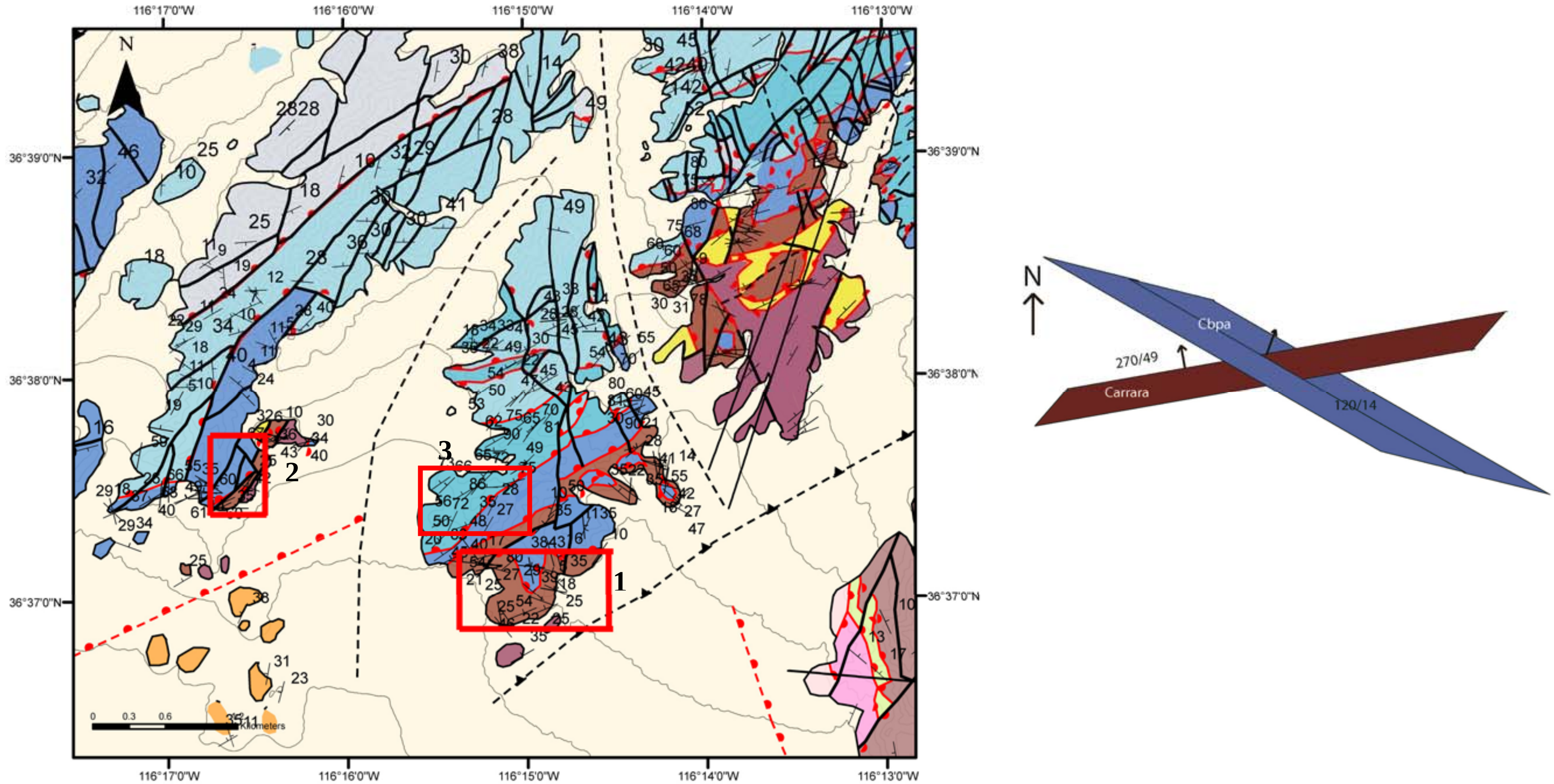


Figure 23. Map illustrating the relationship between the Carrara Formation and lower Bonanza King Formation. The Carrara (brown) strikes west to northwest and Cbpa (navy) generally strikes north (red box #1). The nature of the detachment in the area of red box #2 is illustrated in the diagram to the right of the map, where the detachment surface is parallel to the strike of the underlying unit and cuts obliquely down section. Box #3 shows the rotation of the beds in the hanging wall of the detachment between Cbpa and Cbpb/Cbpc to nearly vertical. For detailed structural and lithologic explanations, see plate 1.

5.1.5 Middle Bonanza King (Cbpb/Cbpc)

Within the middle Bonanza King a breccia zone more than 30 m thick contains well rounded clasts as large as boulders (Fig. 24). The detachment oringinates at the base of Cbpb. Cbpb is only 60 m thick with silty horizons interspersed throughout the silty limestone and dolomite that makes up the unit, making it a good candidate as a detachment horizon. The clast lithology in the breccia pictured below, varies between the two units (Cbpb/Cbpc). They range from light-to dark-gray in color. Some clasts retain laminations while others are massively bedded. Most of the clasts in this breccia zone are likely sourced from the overlying Cbpc unit and the intervening Cbpb is missing. The detachment cuts up section to the west where it cuts out unit Cbpb so that Cbpc is against Cbpa (Fig. 23 box 3). Beds of Cbpc in the hanging wall strike E-W and dip nearly vertically, whereas the footwall units (Cbpa/Cbpb) dip gently. This indicates that hanging wall beds may have been rotated to vertical along the detachment.

Figure 24. Bouldery breccia defines the detachment between Cbpb and Cbpc. This zone is approximately 30 m thick. Clasts are sub-angular to rounded and range from pebble to boulder in size and are poorly sorted. Photo 5561 (see appendix E for detailed location).

5.1.6 Middle Bonanza King (Cbba)

Previous workers (Sargent and Stewart, 1971) have recognized a disconformable contact, consistent with our interpretation of a stratigraphic detachment, between the Papoose Lake and Banded Mountain members of the Bonanza King Formation. The type section of this unit from the Striped Hills has been measured at 90 m. The section measured along the SRT cross-section (A-A') (see plate 1), was measured at approximately 60 m. Field evidence suggests it has been thinned along its stratigraphic horizon as it, too is extremely brecciated along weak layers. It is also probable that the detachment of the next lowest unit defines the process zone from which Cbba detaches from.

5.1.7 Upper Bonanza King (Cbbc)

The thickness of Cbbc in the Striped Hills is 150 m. In the Specter Range it is only 100 m (Plate 1; A-A'). It is the highest unit of the Bonanza King Formation (Cbbc) and detaches from the unit below it. The best exposure of the detachment surface is in the southeastern Specter Range (Table 2) where light-to medium gray unit over the darker gray, well bedded, unit distinguishes a clearly visible undulating surface is (Fig. 25). Bedding in the footwall is E-W and dips approximately 30^o north. Bedding in the hanging wall is poorly defined but generally slightly steeper than in the footwall.

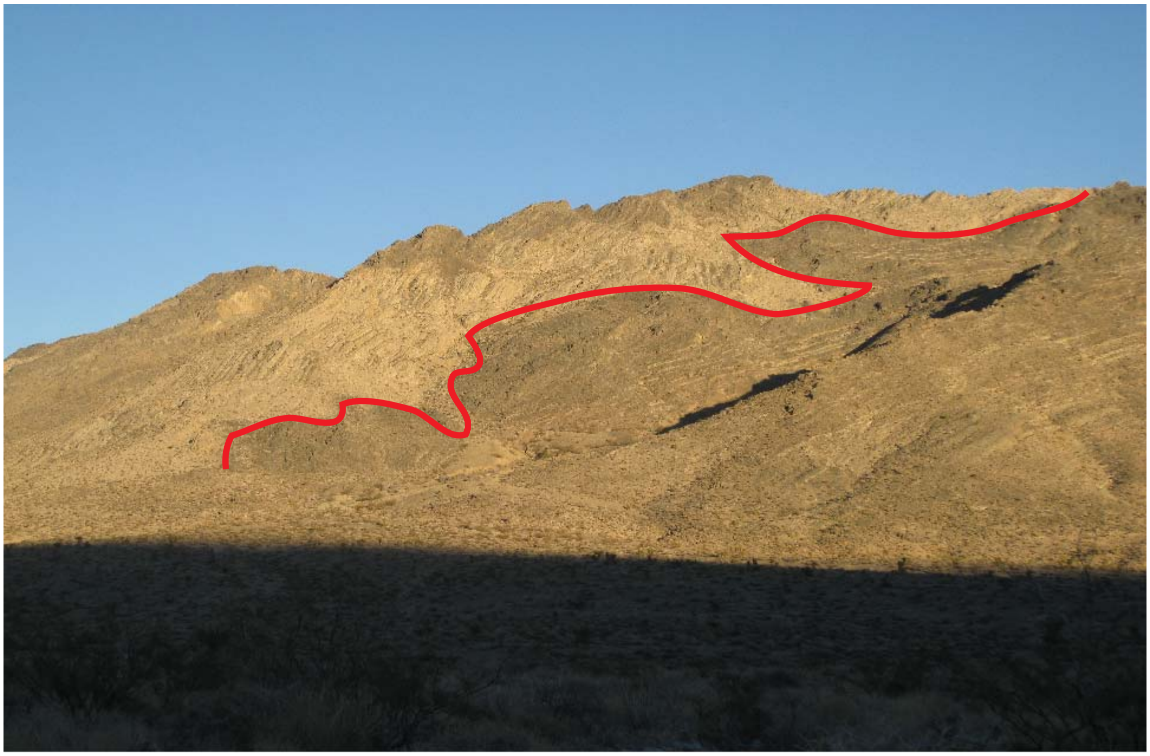


Figure 25. Upper unit, Cbbc, of the Bonanza King Formation shows its irregular detachment surface above tilted lower Bonanza King Formation. Both units strike east-west. The footwall dips approximatly 30 north and the hanging wall is slightly steeper. Approximate location this photo was taken from is UTM Zone 11 N 579352 4049837. The actual map location is denoted by the red box on figure 26.

5.1.8 Dunderberg/Nopah

The Nopah detachment exploits the weak silty and shaly units of the Dunderberg Shale. The Dunderberg/Nopah detachment is probably one of the most significant detachments in the Specter Range as breccias associated with the detachment in the Nopah formation are often tens of m thick (Fig. 27). Stratigraphic relationships in the southeastern Specter Range suggest the Nopah may have been thrusted after it was detached (Fig. 26) This relationship suggests the thrusting of the Nopah Formation is the most recent structural event. In places it is thrust over the Nevada Formation and Antelope Valley Formations (Fig. 26).

The Nopah detachment differs from all the other detachments in the amount of stratigraphy that is missing varies greatly from one locality to the other. For example in the southeastern Specter Range/northern Spring Mountains over 3,000 m is missing as the Nopah sits on the Precambrian Stirling Quartzite (Fig. 25) (Plate 1: A-A').

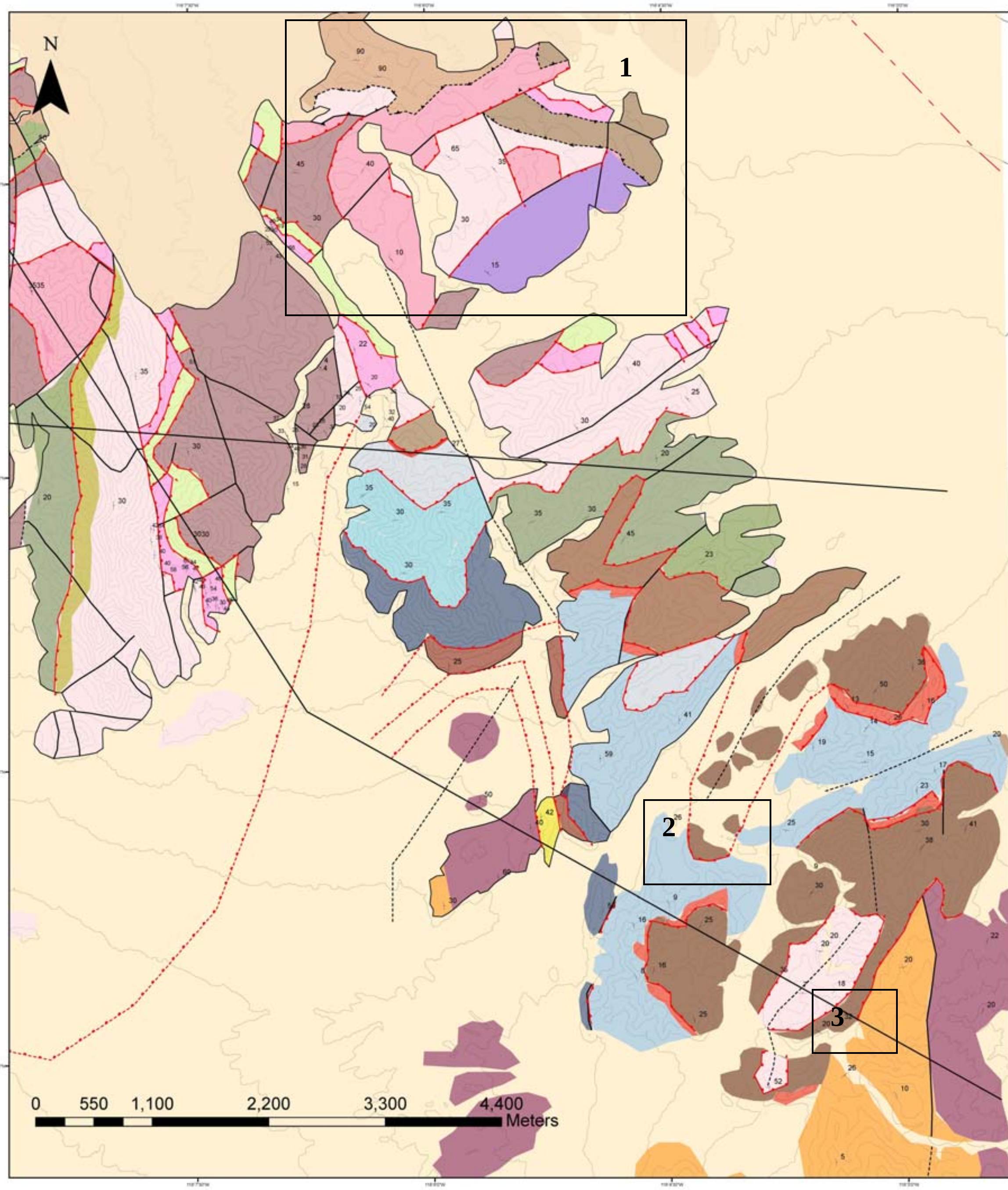


Figure 26. Stratigraphic relationships of the Nopah Formation as a detachment and as a thrust. The area in the black box #1 shows the Nopah thrust on top of Nevada Formation. Box #2 shows the Nopah on top of the Bonanza King with the Dunderberg missing in between. Box #3 shows Nopah sitting on the Stirling quartzite illustrating nearly 2,000 m of stratigraphic separation. For structural and lithologic explanation see plate 1. Map was modified from (Burchfiel, 1965 and Piaschyk, 2007)

Figure 27. Photo of Dunderberg/Nopah detachment. The Nopah is heavily brecciated but retains gross bedding as evidence by its alternating light and dark gray stripes. The red line indicates the detachment surface. Photo from (Piaschyk, 2007).

5.1.9 Ninemile/Antelope Valley

The Ninemile Formation contains abundant silty and shaley units conducive to detaching (Merriam, 1963). Furthermore there is a change in bedding (Fig. 28) between the Goodwin and Ninemile Formations at the locations listed in Table 2. Beds in the Goodwin Limestone strike northwest and dip approximately 35^o northeast. Bedding in the Ninemile and Antelope Valley Formations strikes north and dips similarly. The variation in bedding is approximately 15º clockwise from the Goodwin to the Ninemile/Antelope Valley but is consistent across the contact. Where the Ninemile Formation has been cut out the Antelope Valley Formations sits on top of the Goodwin Formation and it is then referred to as the Antelope Valley detachment.

The Ninemile/Antelope Valley detachment is well recognized from a distance. Satellite imagery from Google Earth (Fig. 28), illustrates this relationship on a larger scale. Looking due east on the Satellite imagery on the western side of the hill is the Goodwin Limestone through Antelope Valley section. The red line is the detachment surface at the base of the Ninemile Formation and the white lines above and below it are bedding form lines. The bedding in the Antelope Valley Formation is parallel to the detachment. Bedding in the underlying Goodwin Limestone, however, is cut obliquely, down section, by the detachment.

Figure 28. White lines parallel to bedding in the Goodwin Are truncated against the detachment (red line) within the Ninemile and the red lines indicate a detachment surface. The Ninemile Formation cuts the Goodwin Formation obliquely down section. North is towards the bottom of the page.

5.1.10 Eureka/Ely Springs

The original thickness of the Eureka Quartzite just south of the SRT is approximately 140 m (Burchfiel, 1964). Average thickness of the Eureka through out southern Nevada is typically 90 m. The reason for such a thick section at this locality is not known. However, the thicknesses further south are only 45 m. If the 140 meter section is considered to be its original thickness then nearly 100 m of the Eureka are missing. Detachments in the Eureka are marked by intense fracturing, brecciation and may be folded (Fig. 29). At the location pictured below, the detachment is folded appears as if it were moving along topography, likely older north-south folds. The fold hinge pictured below trends NNE consistent with these older topographic features. This type of detachment morphology is probably widely prevalent through out the field area but not well preserved in the carbonate section. The resistant quartzite units illustrate this morphology well. A folded detachment can also be seen in another locality in the Stirling Quartzite (Piaschyk, 2007).

Figure 29. Folded detachment in Eureka Quartzite. The detachment is within the stratigraphic section but appears to have folded back on itself in response to coming in contact with an area of higher topography. The Eureka is probably the only unit to preserve this feature as the carbonate section above and below are more susceptible to weathering. Location UTM Zone 11N 572978 4054072.

The detachment of the Eureka Quartzite onto the Antelope Valley Formation is locally steeper than the horizontal detachments typical of the study area. Bedding on both sides of the detachment is completely obscured by intense brecciation (Fig. 30). It's difficult to know if this detachment was once sub-horizontal and has been steepened or it if it mimics what was once bedding that is now obliterated by brecciation. What may be remnant bedding in the Eureka Quartzite appears to be dipping parallel to the detachment surface and is highlighted in white, (Fig. 30) supporting the latter.

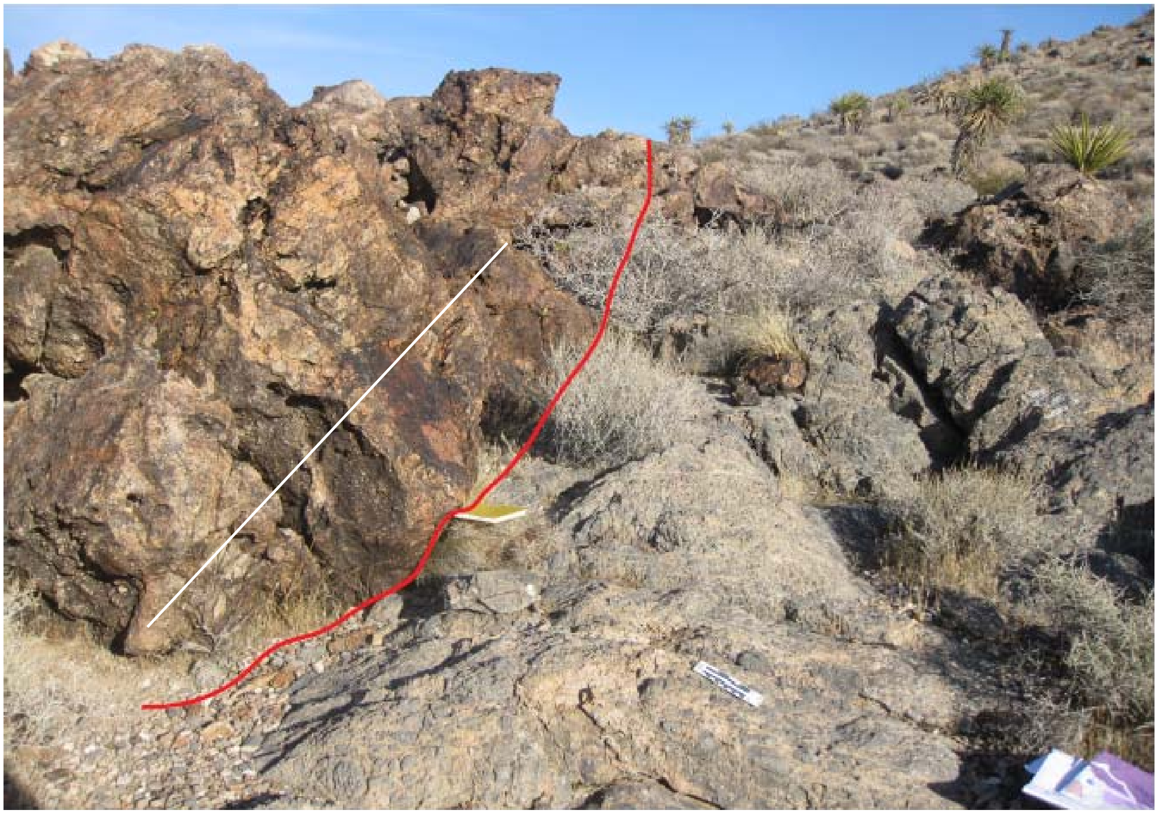


Figure 30. Steep detachment surface between the Eureka Quartzite and Antelope Valley Formation is indicated by the red lin. The white line shows possible remnant bedding in the Eureka above the detachment. It is difficult to discern bedding in the underlying Antelope Valley. Located UTM Zone 11N 580156 4051420.

The original thickness of the Ely Springs Formation is 140 m. In the southern Specter Range its thickness is thinned by 100 m, similar to the attenuated thickness of the Eureka Quartzite. At the basal contact of Ely Springs Dolomite with Eureka, the dolomite is typically brecciated (Fig.31). However, the brecciation doesn't persist throughout the whole unit and the upper beds of the formation tend to be well bedded. Therefore, the detachment of the Eureka from the Antelope Valley is probably the principle detachment responsible for brecciation at the base of the Ely Springs. Breccaition at the base of the Ely Springs is simply the process zone of the detachment at the base of the Eureka. Evidence is supported by complete brecciation of the Eureka Quartzite in some localities. Breccia associated with the Ely Springs Dolomite predominantly contains pebble to small cobble sized clasts and is cemented in a pink to orange matrix. The pink matrix is interpreted to have formed with some varying component of water (Fig. 31).

Figure 31. A. Detachment marked by the red line between the Eureka and the overlying Ely Springs. Notice the Eureka retains little bedding and is missing the dolomite unit commonly found at the top of the unit, and that bedding in the Ely Springs has been disturbed as well. Photo B is a close up of the Eureka near the contact of the detachment. Photo C is an example of Ely Springs just above the detachment. Photo location UTM Zone 11 N 569882 4052206.

5.1.11 Undifferentiated Silurian Rocks

Burchfiel, 1964 measured these rocks to be 670 m thick at the type locality. The unit thickness in the Specter Range cross-section (A-A’) is only 250 m. Over 500 m of attenuation have occurred. Unique to this unit is a series of steeply dipping slide surfaces with an average strike of 220 degrees (Fig. 32). These surfaces are likely related to intra-detachment motion so that they form steep angles with the typically sub-horizontal detachment surfaces. It is also possible, however that these slide surfaces are primary detachment features which have been rotated to nearly vertical. The slide surface in Figure 32b supports the notion that these features formed intra-detachment as it obliquely cuts bedding at a 45º angle.

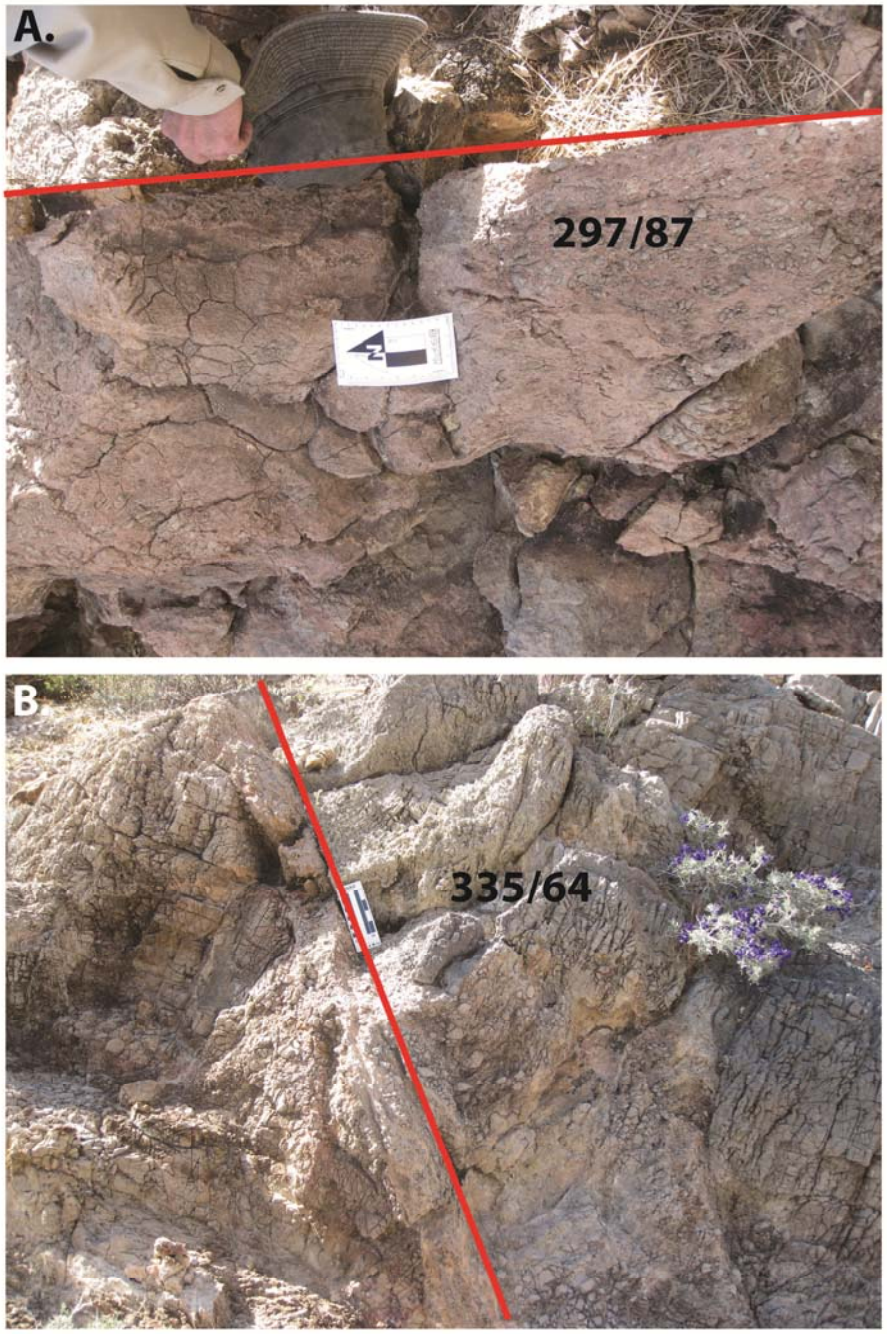


Figure 32. Figure 32. Slide surfaces in undifferentiated Silurian rocks in the southern Specter Range illustrated by the red lines. A) Slide surface measures 297/87 and is located in UTM Zone 11N 570811 4049382. Photo B measures 335/64 and cuts bedding at approximately 45º Photo location is UTM Zone 11N 579935 4051371

5.1.12 Nevada

The Nevada Formation is comprised of two units, totaling 500 m. The lower member, 140 m, is predominantly quartzite with silty dolomitic interbeds becoming more abundant towards the top of the unit. The silty units probably accommodated detachment between the Lower and Upper Nevada Formation. The thickness measured in the Specter Range cross-section (A-A’) is only approximately 160 m, for over 300 m of thinning along the basal contact of the upper unit.

5.2 Structural Interpretations

The southern basin and range, in particular the Nevada Test Site and areas of interest to the south deviate away from classic basin and range structure. Here, north-south basin and ranges appear to have been rotated, accommodated by right-lateral movement along the LVVSZ. Further accommodation of the restraining bend in the LVVSZ is seen in the severe thinning along stratigraphic detachments.

It has been well documented that severe thinning and brecciation has occurred along the previously discussed detachment horizons. In some cases entire units are missing. The best example is the contact of the Wood Canyon and Bonanza King Formation just north of the SRT. The Carrara and first two units of the Papoose Lake Member are missing so that Cbpc sits directly on top of an already severely thinned Wood Canyon Formation. Throughout the study area most units are thinned along detachment horizons but none exhibit the stratigraphic separation north of the SRT. It's likely that most of the offset of the LVVSZ is accommodated along that contact. Detachments throughout the rest of the study area accommodate the thinning that is seen at the SRT throughout the entire Precambrian to middle Paleozoic section.

Stratigraphic order throughout the field area is generally preserved. However, some stratigraphic relationships in the southern Specter Range allows for temporal interpretation of these detachments. For example, there are several places where the Antelope Valley and the Ely Springs formation come in contact and cut out the Eureka suggesting the Antelope Valley detachment post-dates the detaching of higher stratigraphic units. The Nopah thrust relationship previously discussed also must post-date Nopah detaching as it covers the detachment surface between the Nopah and Antelope Valley Formations.

One area which does not seem to experiencing the same deformational style as the Specter Range is the Striped Hills. This is likely do to their isolation from the Specter Range via the RVF. O'Leary, (2000) has interpreted it as a left-lateral fault co-genetic with the Walker Lane that accommodates extension between the Spring Mountains the Southwestern Nevada Volcanic field.

Localized structures within the Specter Range likely form a direct response from the large regional structures that probably have the most significant influence on groundwater flow. Such severe brittle deformation and detachments appear to be localized in the Specter Range and Northern Spring Mountains. This deformation style however, is probably a response to a much larger tectonic setting, as detachments and contractional structures such as the SRT form in response to the overall regional structure imposed by the LVVSZ. Furthermore, fracture patterns in the field area help to understand which episode of Cenozoic extension has the greatest influence on the current arrangement of the carbonate aquifer and related clastic aquitard. Understanding these faults is crucial to groundwater flow, as they likely have been reactivated two or more times. A prolonged history and reactivation of a fault allows to it to penetrate to greater depths and influence groundwater flow paths in the regional carbonate aquifer.

6.0 Hydrology

The Nevada Test Site sits entirely within the Death Valley regional flow system (Fig. 33). There are three different aquifer types on the Nevada Test Site. From lowest to highest they are the carbonate aquifer, the volcanic aquifer and the valley fill aquifer. This research focuses predominantly on the carbonate aquifer. However it is the stratigraphically lowest aquifer, therefore water sourced from higher aquifers has the potential to be integrated into the regional aquifer and travel great distances. The carbonate aquifer is responsible for regional groundwater flow and is probably hydraulically connected with the localized volcanic and valley fill aquifers. Groundwater depths within the carbonate aquifer range from 500 m from the top of the aquifer to 1200 m beneath the land surface (Winograd and Thordarson, 1975). Intra-basin movement between the two local aquifers to the regional carbonate aquifers allows for inter-basin flow. This pattern of groundwater movement ultimately channels most of the groundwater from the northern and eastern half of the Nevada Test Site southwestward towards Ash Meadows (Fig. 2).

Groundwater in the DVRFS moves predominantly southwest towards Ash Meadows. Potentiometric contours on the NTS illustrate this trend (Fig. 33), as areas of high topography are widespread in the northern NTS providing recharge to the regional flow system. Head decreases from 1,500 m at Ranier Mesa to 700 m in Amargosa Valley for a hydraulic gradient of .01.

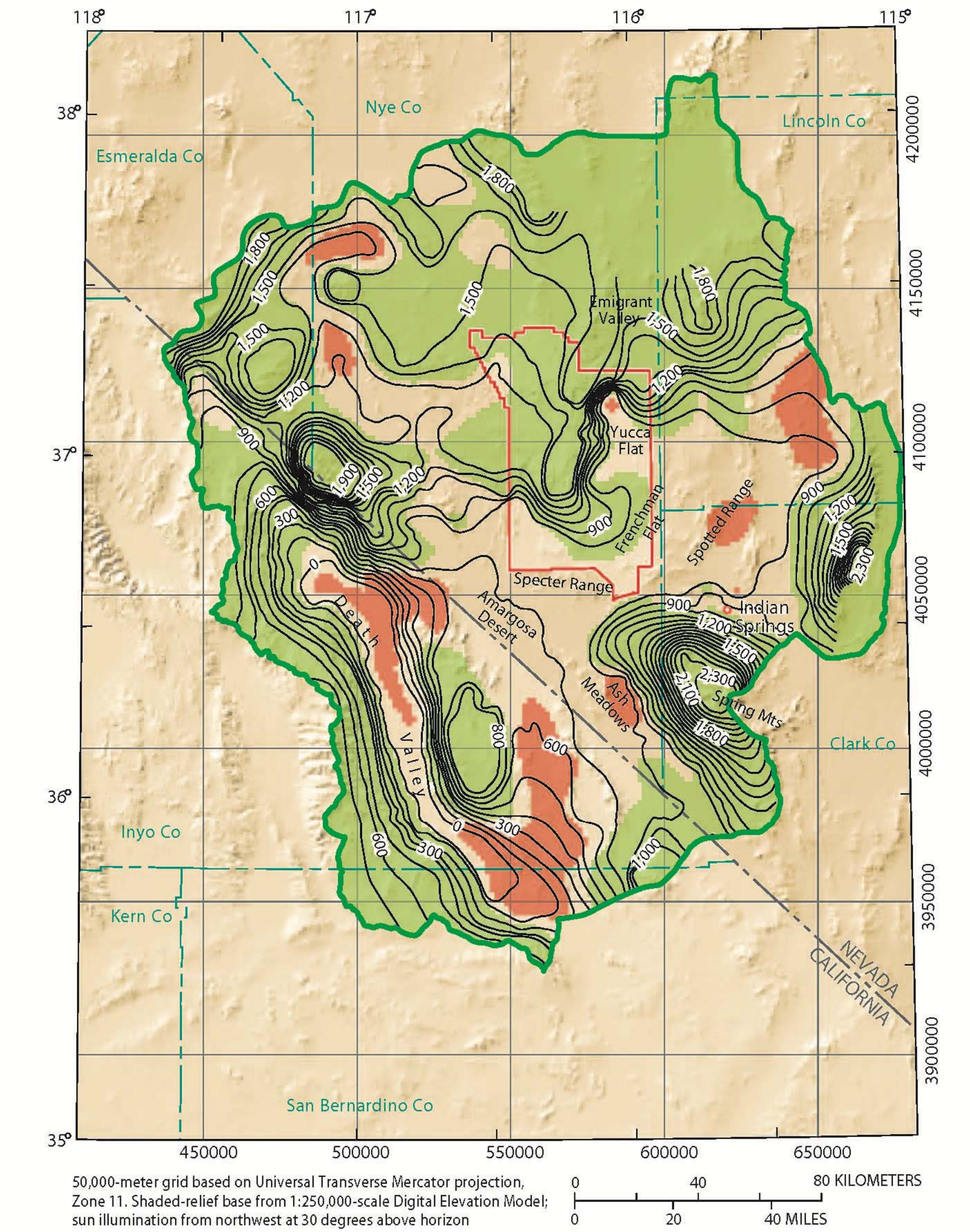


Figure 33. Potentiometric contours within the DVRFS (outline in green). Contour interval is 100 m. Areas of green are potential areas of rechrage and red areas indicate discharge zones. Figure from Belcher et al., (2010)

The carbonate aquifer is one of the most conductive units on the NTS (Pohlmann et al., 1996). Hydraulic conductivities in the carbonate aquifer have been measured between .09 and 731m/day (Pohlmann et al., 1996). The greatest impact on hydraulic conductivity at any given point within the flow system is the hydraulic gradient, which can locally be very high on the NTS. One of the largest and most voluminous flow paths in the DVRFS originates to the east in the area of Frenchman Flat and flows WSW towards Ash Meadows, labeled the Ash Meadows flow system on (Fig. 2). Furthermore the Rock Valley tributary flow system is likely just as important.

Discharge rates of the Rock Valley tributary flow system have been measured at less than 1000 acre-ft/year. The change in head from the northern extent of the flow system near Yucca Flat and the southern end, presumably at the Hwy. 95 fault, is only 15 m (Fenelon et al., 2010) and steepens slightly as it approaches the terminus of the flow system near Hwy. 95. Some workers (Sweetkind et al., 2004) have suggested the Hwy. 95 fault impedes groundwater flow acting like a dam, as evidenced by paleospring deposits found along its suggested trace. Hydraulic head data suggests a possible linkage between the Rock Valley and Yucca Flat tributary flow systems as it extends southward into Frenchman Flat intersecting the up gradient portion of the Rock Valley tributary flow system.

The Ash Meadows flow system appears to be hydraulically independent from the Rock Valley Tributary flow system, suggesting the SRT may act as a sufficient aquitard in the same manner a non-welded tuff acts as an aquitard. Instead the Spring Mountains tributary flow system to the south and the Belted Range tributary flow system are integrated in the Ash Meadows flow system (Laczniak et al., 1996).

6.1 Aquifers and Aquitards

The juxtaposition of aquifers and aquitards (Fig. 34) via fault motion likely has a first order effect on hydraulic gradients and flow paths. The lateral extent at which the carbonate aquifer crops out on and adjacent to the NTS is localized, as it has been covered by rocks associated with extensional volcanism of the Southwestern Nevada Volcanic Field. It is likely, however that the volcanic and carbonate aquifers hydraulically communicate. The Carbonate aquifer is composed of rocks from middle Cambrian through Devonian age. Throughout most the Death Valley regional flow system the carbonate aquifer is saturated.

The Wood Canyon Formation, Zabriskie Quartzite and the Eureka Quartzite are the three primary confining units within the carbonate aquifer system postulated to impeded groundwater flow (Fig. 5). The degree of fracturing or brecciation that these units experience may limit their efficiency as confining units. For example, where the Eureka Quartzite is not brecciated it is intensely fractured. Fracture sets typically occur 45 degrees to one another. Brecciated Eureka Quartzite is well cemented suggesting it still serves as an efficient aquitard. The Wood Canyon Formation doesn’t experience nearly as much brecciation as the Eureka Quartzite but is typically fractured as well. The Zabriskie Quartzite is often missing the study area as it has been thinned via the detachment between itself and the underlying, Wood Canyon Formation. Coupled with a lack of well data, its merits as a confining unit may not be fully understood.

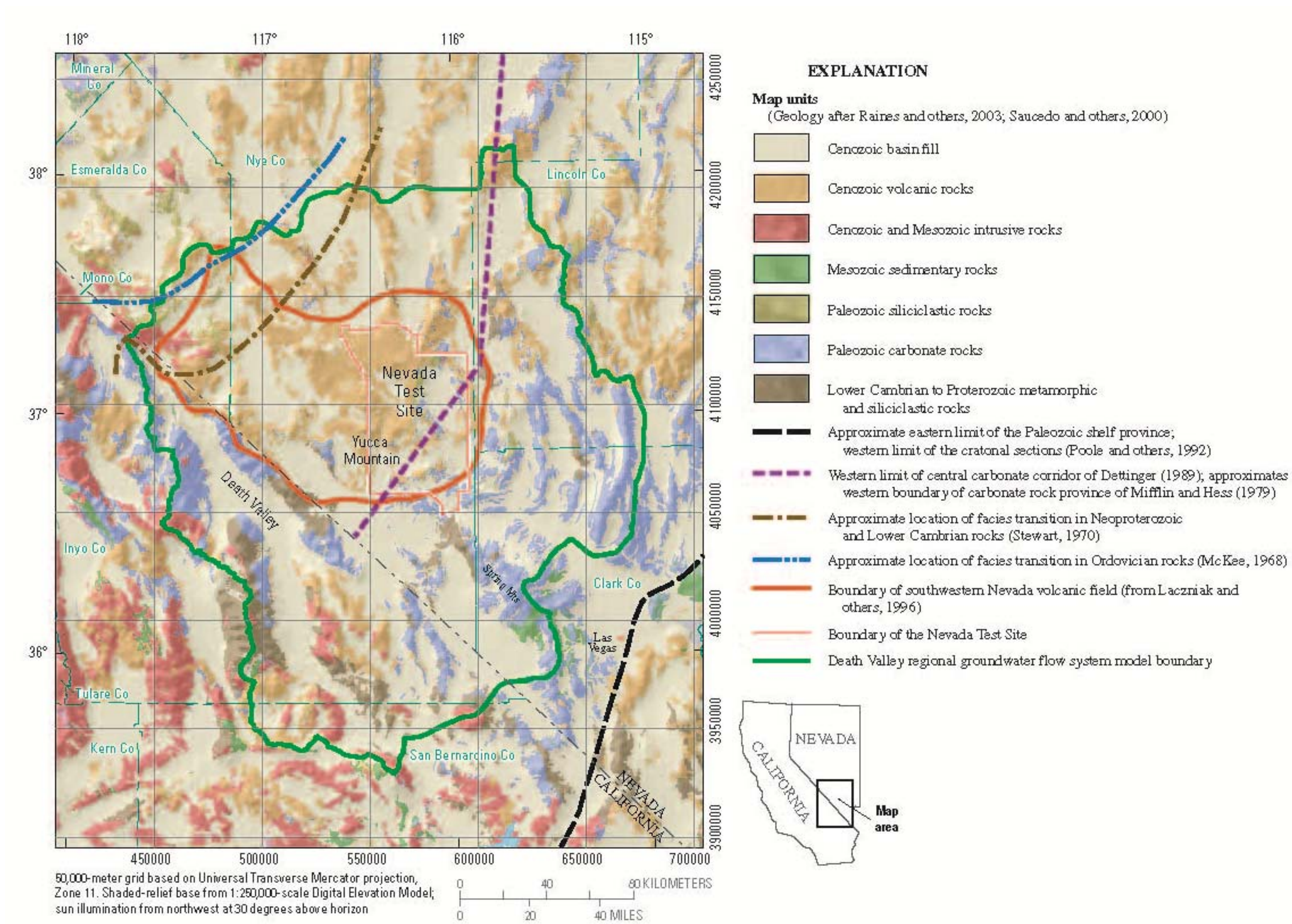
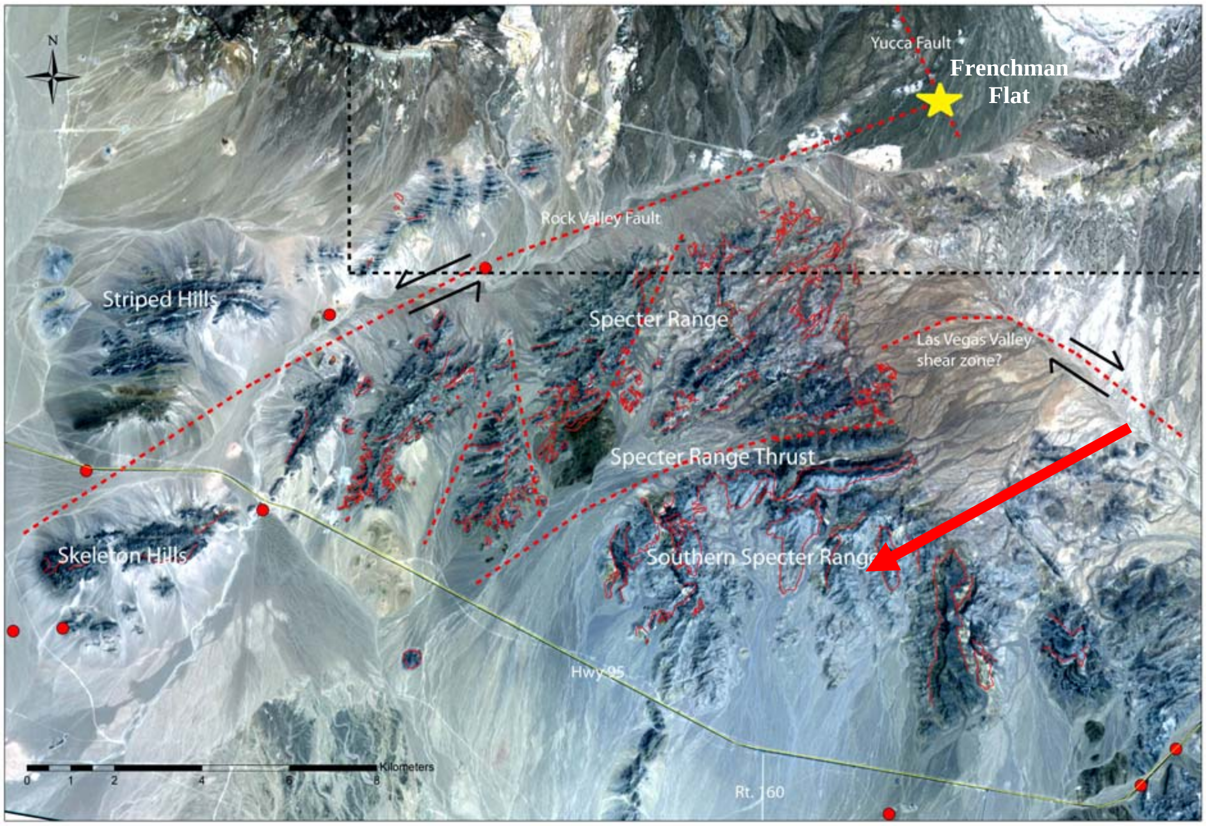


Figure 34. Map showing the regional distribution of aquifers and aquitards within the Death Valley regional flow system. The red box denotes location of field area. Figure modified from (Belcher and Sweetkind, 2010).

6.2 Structural Hydrologic Controls

The carbonate aquifer of the Ash Meadows flow system is probably structurally controlled by the ENE striking faults, the SRT and RVFs. The SRT emplaces Cambrian carbonates atop the Precambrian Wood Canyon Formation. If this powder like consistency projects to water table depths it is possible that it acts as a confining unit in the same way the non-welded tuff unit behaves with respect to the welded tuff and alluvial aquifers. The hydraulic isolation between the Ash Meadows flow system and the Rock Valley tributary flow system support it's efficacy as a barrier to groundwater flow, locally.

As previously mentioned, hydraulic connectivity between the Rock Valley and Yucca Flat tributary flow systems is suggested by examining hydraulic head across the two areas. Both flow systems are likely controlled by large geologic structures, the RVF and Yucca Fault, respectively (Fig. 35). Furthermore, examining potentiometric contours (Fig. 33) reveals one of the highest hydraulic gradients on the NTS boarders the Yucca Fault on its western side and at its northern most extent. With the southern termination of the Yucca Fault in the vicinity of Frenchman Flat and northern end of the RVF probably covered by alluvium at the same locality, there is almost certainly groundwater communication between the two faults. It may flow SW down the RVF directly into Amargosa Valley. There is also potential for groundwater to flow down any of the north-south splays of the RVF which offset segments of the northern Specter Range.



ASTER satellite imagery in the of the area of Plate 1. Map is projected in UTM NAD 1983 Zone 11 N.

Detachments Faults NTS Boundary Nye County Propsed pizeo wells Proximal location of suggested well

Figure 35. Detachments drawn on ASTER satellite imagery are indicated by the solid red lines. Key geologic structures are pointed out on the map. The red dots are locations of Nye County proposed pizeo wells. The yellow star denotes the approximate suggested location of a well to be drilled at the intersection of the Yucca fault and Rock Valley fault. The red arrow denotes a fast flow with high volumes of water south of the Nevada Test Site.

7.0 Conclusions

The Nevada Test Site is a structurally complex region in the Basin and Range Province of western North America that has experienced several episodes of compressional and extensional deformation. Understanding its structural synthesis is important to determine groundwater flow paths south of the Nevada Test Site, as well as for future of nuclear waste disposal at Yucca Mountain.

There are several key structures in the study area which are likely to influence groundwater flow. They are the SRT and the RVF zone. The LVVSZ does not enter the study area but is postulated to link with the SRT (Burchfiel, 1965) and the Walker Lane extensional domain further west (Stewart, 1988). The 30 miles of right-lateral offset is well documented from Las Vegas to Indian Springs (Fig. 14) but is not discernible in the Specter Range. Detailed field mapping over a span of approximately eight weeks suggests the severe thinning and brecciation of the carbonate aquifer and clastic aquitard by as much as 35% via stratigraphically controlled detachment horizons. The severe brecciation coupled with the dissolution of the carbonate aquifer suggests groundwater will flow readily through it and on to Amargosa Valley and Ash Meadows, ultimately discharging to Death Valley. Furthermore, if contaminated groundwater reaches the RVF, containing it will be very difficult and the north-south splays that cut through the Specter Range have the potential to transport water as well. Therefore, drilling a well in the vicinity of the intersection of the Yucca Fault and Rock Valley Fault maybe advantageous to further understanding groundwater flow southwest of the Nevada Test Site.

APPENDIX A

Table 3. Bedding data with waypoint location numbers and corresponding lithology. See Plate 1 for lithologic abbreviations. All data was measured in NAD 1927 and reprojected in NAD 1983 for use in ArcMap.

WAYPOINT	ZONE	EASTING	NORTHING	LITHOLOGY	BEDDING	
					STRIKE	DIP
010410-1	11	562236	4057872	Cbb	280	35
010410-4	11	561954	4057690	Cbb	275	88
010510-2	11	559029	4056106	Cc	104	53
010610-3	11	559281	4055434	Cpcw	238	22
010610-5	11	559231	4055371	Cpcw	080	64
010710-1	11	559915	4056152	Cc	254	85
010710-5	11	560091	4057302	Cbb	270	70
010810-1	11	561769	4057604	Cbb	290	90
010810-3	11	561635	4057931	Cbb	281	47
010810-6	11	563164	4056524	Cc	190	46
010910-1	11	563556	4053723	Cbp	020	58
010910-1	11	563556	4053723	Cbp	020	58
010910-2	11	563915	4053608	Cbp	191	59
010910-3	11	564103	4053839	Cbb	280	19
010910-4	11	564225	4054047	Cbb	208	05
011010-1	11	563725	4053146	Cbb	246	18
011010-1	11	563725	4053146	Cbp	346	29
011010-1	11	563725	4053146	Cbp	314	29
011010-5	11	563935	4053447	Cbb	239	40
011010-6	11	564045	4053479	Cbb	005	37
011010-7	11	564110	4053522	Cbb	000	26
011010-8	11	564236	4053461	Cpcw	250	58
011010-9	11	564238	4053463	Cpcw	243	66
011010-14	11	564385	4053519	Cc	278	61
011010-15	11	564401	4053569	Cbp	120	14
011010-15	11	564401	4053569	Cc	270	49
011010-16	11	564428	4053540	Cbp	120	55
011010-18	11	564428	4053508	Cc	270	35
011010-22	11	564645	4053383	Cbpa	120	24
011010-22	11	564645	4053383	Cc	270	35
011010-26	11	564750	4053562	Cc	290	42
011010-27	11	564751	4053608	Cbpa	217	25
011210-5	11	570766	4049715	Dsdu?	013	60
011210-6	11	570805	4049740	Dsdu?	305	62
011210-7	11	570814	4049759	Dsdu?	043	62
011210-8	11	570674	4050236	Oa	168	24
011210-9	11	570687	4050316	Oes	163	19
011210-11	11	571019	4050754	Oe	155	21
011210-12	11	570910	4050761	Oes	178	32
011210-16	11	570636	4050383	Oes	340	42

011210-17	11	570889	4049157	Dsdu?	050	58
011310-6	11	579209	4051079	Dsdu?	320	34
011310-7	11	579031	4051227	Dsdu?	334	25
011310-8	11	579031	4051227	Dsdu?	330	33
011310-9	11	578986	4051348	Dsdu?	325	37
011410-1	11	567020	4052153	Cpcw	240	35
011410-2	11	566878	4052390	Cc	320	25
011410-3	11	566924	4052443	Cc	325	22
011510-1	11	567526	4050916	Cz	240	28
011510-3	11	570650	4056003	Cbpa	072	18
011510-4	11	568336	4053376	Cc	299	47
011510-6	11	568318	4053448	cbpa	231	36
011510-7	11	568286	4053470	Cbpa	311	27
011510-10	11	568208	4053598	Cbpa	190	42
011510-12	11	568183	4053713	Cc	000	39
011510-13	11	568167	4053713	Cc	025	61
011510-14	11	568150	4053733	Cc	350	55
011510-15	11	568135	4053739	Cbpa	290	42
011510-17	11	568121	4053756	Cbpa	284	41
011610-2	11	565232	4053930	Cc	075	34
011610-2	11	565232	4053930	Cc	045	30
011610-2	11	565232	4053930	Cc	078	40
011710-1	11	563768	4053061	Cbpa	290	34
011710-3	11	564979	4053922	Cc	053	67
011710-5	11	564977	4053950	Cc	072	32
011710-5	11	564977	4053950	Cc	105	43
011710-5	11	564977	4053950	Cc	100	36
011710-5	11	564977	4053950	CC	252	32
011710-5	11	564977	4053950	Cc	285	43
011710-5	11	564977	4053950	Cc	280	36
011710-6	11	564990	4053987	Cc	265	10
011710-10	11	564889	4053949	Cpcw	305	06
011810-1	11	569755	4055793	Cc	255	05
011810-3	11	569699	4055841	Cpcw	267	12
011810-5	11	569550	4056285	Cc	258	13
011810-6	11	569543	4056312	Cc	255	40
011810-8	11	569483	4056316	Cc	243	21
011810-10	11	569429	4054323	Cpcw	225	30
011810-12	11	569379	4054016	Cpcw	250	11
031510-1	11	562433	4054428	Cbpc	050	15
031510-2	11	562482	4054504	Cbpc	336	02
031510-3	11	562502	4054524	Cbpc	333	03
031610-1	11	569693	4056241	Cbpa	055	75
031610-4	11	569792	4056479	Cbpa	240	45
031610-7	11	569982	4056433	Cc	240	23
031610-16	11	570150	4056031	Cc	230	16
031610-18	11	570132	4056000	Cbpa	245	26
031710-7	11	573739	4054200	Oa	225	20
031710-9	11	573762	4054288	Oa	090	20
031710-11	11	573868	4054347		200	25

031710-15	11	573611	4053976	Og?	100	45
031810-2	11	569786	4054826	Cz	225	61
031810-3	11	569760	4054772	Cz	200	70
031810-5	11	569498	4055060	Cz	281	30
031810-6	11	569435	4055038	Cz	247	36
031810-8	11	569410	4055042	Cz	262	38
031810-9	11	569338	4055128	Cz	191	25
031810-15	11	569109	4054873	Cz	245	28
031810-16	11	569057	4054688	Cz	245	30
031810-17	11	569060	4054643	CPCW	295	15
031910-2	11	568879	4054465	CC	278	10
031910-3	11	568876	4054501	CC	267	10
031910-4	11	568795	4054453	CC	280	05
031910-6	11	568735	4054460	CPCW	250	43
031910-7	11	568733	4054465	CPCW	263	68
031910-11	11	567979	4054056	Cbba	065	90
031910-12	11	567988	4054040	Cbpb	085	81
031910-13	11	567994	4054011	BK/CC?	060	90
031910-15	11	567956	4054023	Cbpb	255	80
031910-17	11	568064	4053991	CC	200	60
031910-18	11	568056	4053954	Cbpa	250	45
031910-20	11	568133	4053744	Cc	275	33
031910-21	11	568041	4053671	CC	230	28
031910-22	11	568058	4053690	Cc	255	21
032010-1	11	568780	405800	Cc	330	10
032010-2	11	568786	4054823	Cpcw	296	10
032010-3	11	568741	4055129	Cc	240	46
032010-5	11	568903	4055394	Cpcw	285	27
032010-6	11	568905	4055396	Cpcw	248	40
032010-7	11	568900	4055394	Cpcw	327	05
032010-8	11	568900	4055392	Cpcw	265	35
032010-9	11	568967	4055455	Cpcw	297	08
032010-10	11	568986	4055480	Cc	270	22
032010-11	11	568993	4055490	Cc	293	37
032010-12	11	569013	4055499	Cc	285	47
032010-13	11	568936	4055554	Cpcw	290	12
032010-14	11	569037	4055633	Cc	193	28
032010-15	11	569049	4055633	cbpa	254	67
032010-17	11	569007	4055676	Cc	225	26
032010-18	11	569066	4055801	Cc	264	22
032010-19	11	568879	4055793	Cc	255	35
032010-20	11	568866	4055791	Cc	254	67
032210-2	11	567983	4054417	Cbb	230	55
032210-3	11	567904	4054552	Cbb	230	60
032210-4	11	567844	4054559	Cbb	240	70
032210-5	11	567717	4054653	Cbb	270	54
032210-6	11	567610	4054693	Cbb	257	42
032210-7	11	567588	4054751	Cbb	320	14
032210-11	11	567482	4054808	Cbb	273	25
032210-12	11	567405	4054806	Cbb	277	38

032210-13	11	567364	4054744	Cbb	265	43
032210-14	11	567369	4054689	Cbb	245	45
032210-15	11	567393	4054615	Cbb	280	28
032310-2	11	570535	4057407	Cbb	280	25
032310-4	11	570447	4057593	Cc	305	23
032310-5	11	570429	4057632	Cc	310	16
032410-1	11	568390	4054967	Cc	297	30
032410-2	11	568415	4055027	Cc	260	31
032410-6	11	568507	4055152	Cc	230	65
032410-7	11	568470	4055211	Cc	240	50
032410-10	11	568333	4055213	Cc	225	35
032410-11	11	568305	4055207	Cc	220	60
032410-12	11	568176	4055173	Cc	205	60
032410-15	11	568277	4055333	Cc	093	75
032410-16	11	568366	4055293	Bk	050	68
032410-17	11	568528	4055511	Cc	074	86
032410-18	11	568743	4055783	Cc	225	64
032410-19	11	568669	4055889	Cc	225	75
032410-20	11	568610	4055881	Cc	225	80
032410-21	11	568513	4055056	Cc	280	19
032510-2	11	571223	4053570	Oa	130	23
032510-4	11	571225	4053517	Oe	127	05
032510-12	11	570887	4053177	Oa	155	12
032610-4	11	570131	4052232	Oes	355	10
032610-11	11	570988	4054956	Cc	257	23
032610-12	11	570942	4054721	Cc	302	20
032610-13	11	570946	4054704	Cc	350	50
032610-14	11	570946	4054709	Cc	290	10
032610-15	11	570970	4054643	Cc	355	11
032610-16	11	570998	4054639	Cc	285	13
032610-17	11	571047	4054670	Cc	274	24
032610-18	11	571057	4054676	Cc	145	90
032610-19	11	571131	4054715	Cns	180	10
032610-22	11	571324	4054923	Cc	250	45
032610-23	11	571051	4054633	Cc	265	14
032710-1	11	571988	4055175	Cc	260	16
032710-2	11	572238	4055297	Cc	260	45
032710-4	11	571618	4055115	Cc	315	13
032710-5	11	571612	4055133	Cc	247	13
032710-6	11	571405	4054919	Cc	235	30
032710-7	11	571246	4054639	Cc	225	27
032710-8	11	573603	4054946	Og?	250	12
032710-10	11	573568	4055221	Cc	320	08
032710-11	11	573661	4055252	Cc	260	12
032710-12	11	573866	4055071	Og?	163	20
032710-13	11	573923	4055401	Cc	245	03
032710-15	11	574268	4055362	Cc	260	32
032710-17	11	574304	4055008	Oa	185	09
032810-1	11	566512	4052762	Cc	243	20
032810-3	11	566612	4052738	Cc	275	21

032810-4	11	566692	4052834	Cbpc	323	11
032810-5	11	566712	4052831	Cc	285	45
032810-6	11	566745	4052820	Cc	272	20
032810-7	11	566799	4052782	Cc	255	25
032810-8	11	566825	4052724	Cc	280	25
032810-13	11	566898	4052677	Cc	285	27
032810-14	11	567006	4052734	Cc	230	17
032810-17	11	567186	4052702	Cc	275	38
032810-18	11			Cc	295	17
032810-19	11	567196	4052655	Cc	350	80
032810-20	11	567208	4052485	Cc	310	29
032910-2	11	567291	4052344	Cbpa	247	25
032910-3	11	567266	4052415	Cc	290	39
032910-4	11	567400	4052499	Cc	295	25
032910-6	11	567370	4052503	Cbpa	280	05
032910-7	11	567412	4052567	Cc	315	35
032910-9	11	567362	4052658	cc	285	18
032910-10	11	567416	4052769	Cc	345	43
032910-11	11	567357	4052798	Cbpa	354	16
032910-13	11	567284	4053052	Cc	225	35
032910-16	11	567339	4053170	Cc	200	10
032910-17	11	567396	4053185	Cc	230	50
032910-18	11	567633	4053025	Cc	355	11
032910-19	11	567639	4052991	Cc	025	35
032910-20	11	567916	4053318	Cc	310	35
032910-21	11	568008	4053311	cc	305	22
032910-22	11	568018	4053308	Cc	005	35
032910-23	11	567737	4052801	Cbpa	215	10
042610-1	11	564513	4055203	Cbb	055	11
042610-2	11	564528	4055149	Cbb	115	09
042610-5	11	564617	4055087	Cbb	175	19
042610-6	11	564637	4055057	Cbb	180	20
042610-10	11	564904	4054945	Cbb	320	12
042610-11	11	564852	4054861	Cbb	245	31
042610-12	11	564789	4054764	Cbb	295	07
042610-13	11	564713	4054776	Cbb	195	80
042610-14	11	564692	4054772	Cbb	238	10
042610-15	11	564533	4054798	Cbb	240	24
042610-17	11	564348	4054705	Cbb	040	11
042610-19	11	564301	4054566	Cbb	235	29
042610-21	11	564294	4054351	Cbb	126	18
042610-22	11	564357	4054265	Cbb	290	10
042610-23	11	364325	4054188	Cbb	270	11
042710-2	11	564285	4052577	Cc	239	25
042710-4	11	564408	4052580	Cpcw	220	43
042710-5	11	564548	4052694	Sz	340	68
042710-7	11	564775	4052298	Sz	205	38
042710-11	11	565327	4054690	Cbb	045	40
042710-13	11	565190	4054647	Cbb	100	28
042710-15	11	565058	4054579	Cbb	200	40

042710-16	11	564979	4054506	Cbb	110	11
042710-17	11	564872	4054316	Cbb	300	11
042710-19	11	564759	4054215	Cbb	310	04
042710-20	11	564833	4054094	Cbb	315	24
042810-2	11	569901	4051945	Oe	310	13
042810-15	11	570077	4051804	Oes	312	17
042810-18	11	570150	4051719	Oes	005	04
042810-19	11	570210	4051671	Dsdu?	135	40
042810-20	11	570244	4051683	Dsdu/Dnu	140	45
042810-27	11	569832	4051468	Oa	203	11
042910-2	11	570196	4050942	Oa	225	45
042910-5	11	570971	4051202	Oa	195	36
042910-8	11	571308	4051307	Oa	250	14
042910-14	11	571543	4051426	Oe	200	21
043010-2	11	564980	4051793	Sz	190	31
043010-7	11	564656	4051251	Sz	240	35
043010-8	11	564694	4051278	Cpcw	342	11
043010-10	11	565127	4051333	Cpcw	257	36
043010-11	11	565095	4051644	Sz	195	23
050110-1	11	566563	4054521	Cbpc	257	36
050110-2	11	566678	4054577	Cbpc	185	22
050110-3	11	566818	4054530	Cbbc	200	18
050110-4	11	566869	4054527	Cbbc	235	34
050110-5	11	567013	4054523	Cbbc	247	33
050110-6	11	567132	4054498	Cbbb	245	41
050110-7	11	567203	4054447	Cbbc	250	52
050110-8	11	567130	4054418	Cbbb	240	38
050110-9	11	567047	4054387	Cbbb	240	52
050110-10	11	566970	4054349	Cbbc	240	49
050110-15	11	567269	4054249	Cbbb	230	22
050110-16	11	567319	4054248	Cbbb	240	43
050110-18	11	567201	4054155	Cbbb	245	45
050110-19	11	567130	4054121	Cbbc	220	52
050110-20	11	567109	4054118	Cbbb	250	50
050110-22	11	567053	4054088	Cbbb	221	50
050110-23	11	567027	4054077	Cbbc	231	47
050110-27	11	566751	4054136	Cbbb	235	54
050210-2	11	566851	4053893	Cbpc	215	53
050210-5	11	567110	4053889	Cbpc	233	62
050210-7	11	567218	4053875	Cbpc	050	81
050210-8	11	567190	4053838	Cbpc	222	70
050210-9	11	567154	4053799	Cbpc	215	75
050210-11	11	567034	4053770	Cbpc	220	65
050210-12	11	566869	4053729	Cbpc	240	62
050210-14	11	566886	4053623	Cbpc	240	90
050210-16	11	567133	4053557	Cbpc	224	71
050210-17	11	567087	4053526	Cbpc	231	63
050210-18	11	567077	4053509	Cbpc	239	49
050210-20	11	567038	4053400	Cbpc	255	75
050210-22	11	567004	4053354	Cbpc	225	75

050210-23	11	566955	4053362	Cbpc	226	90
050210-24	11	566923	4053386	Cbpc	235	73
050210-25	11	566841	4053462	Cbpc	225	65
050210-26	11	566775	4053440	Cbpc	220	72
050210-27	11	566725	4053358	Cbpc	217	63
050210-28	11	566682	4053326	Cbpc	225	61
050210-29	11	566604	4053293	Cbpc	239	86
050210-30	11	566527	4053361	Cbpc	225	66
050310-3	11	566515	4053065	Cbpc	205	50
050310-4	11	566429	4053065	Cbpc	240	56
050310-6	11	566637	4053039	Cbpc	250	72
050310-7	11	566744	4053121	Cbpc	187	35
050310-9	11	566847	4053194	Cbpb	207	28
050310-13	11	566806	4053023	Cbpb	210	27
050310-14	11	566776	4052995	Cbpb	210	55
050310-16	11	566719	4052945	Cbpb	215	27
050310-18	11	566592	4052912	Cbpb	225	48
050310-20	11	566407	4052910	Cbpa	225	50
050310-21	11	566442	4052792	Cc	235	83
050710-2	11	574900	4049102	Dsdu	170	71
050710-11	11	574882	4049323	Dsdu	290	25
050710-12	11	574870	4049327	Dsdu	260	27
050710-13	11	574862	4049355	Dsdu	287	44
050810-1	11	579092	4052699	Oe	006	43
050810-5	11	579003	4052818	Oe	012	53
050810-7	11	578993	4052878	Oa/Oe	237	64
050810-8	11	579004	4052943	Oe	340	29
050810-11	11	579059	4052924	Oes	320	30
050810-19	11	579117	4053049	Oes	340	19
050810-22	11	579102	4053016	Oes	335	40
050810-24	11	579094	4053040	Oes	347	34
050810-27	11	579217	4052770	Oes	020	68
050810-31	11	578286	4051679	Oes	317	51
050910-1	11	579253	4050542	Oa	346	15
050910-2	11	579328	4050721	Oe	359	28
050910-3	11	579345	4050796	Oe	340	31
050910-4	11	579328	4050881	Oa	325	36
050910-6	11	579444	4051104	Dsdu	007	23
050910-7	11	579505	4051125	Dsdu	327	28
050910-8	11	579609	4051071	Dsdu	330	37
050910-10	11	579690	4051226	Oa/Cn	250	20
050910-12	11	579694	4051338	Oa	273	15
050910-14	11	579737	4051400	Oa	345	24
050910-15	11	579849	4051430	Oe	325	25
050910-16	11	580009	4051529	Oe	305	20
050910-18	11	580181	4051401	Oa	322	30
050910-20	11	580170	4051205	Oa	315	32
050910-22	11	580187	4051135	Oa	270	40
050910-24	11	579993	4051079	Oa/Oes	245	25
050910-25	11	579938	4051253	Oa	315	54

050910-26	11	579935	4051371	Oa/Oe	000	14
051010-3	11	572828	4054276	Oes	127	17
051010-4	11	572874	4054216	Oes	115	47
051010-6	11	572906	4054124	Oes	140	21
051010-10	11	573067	4054299	Oes/dsdu	093	44
051010-12	11	573053	4054363	Oes	135	67
051010-14	11	572931	4054360	Oes	240	43
051010-19	11	571099	4054715	Cc	205	40
051010-20	11	571123	4054733	Cc	200	39
051010-21	11	571102	4054694	Cc	190	22
051010-23	11	571085	4054608	Cc	200	10
051010-24	11	571064	4054534	Cc	230	19
051010-25	11	571036	4054499	Cc	253	30
051010-26	11	570956	4054504	Cc?	143	03
051110-1	11	578609	4049291	Oe	215	78
051110-2	11	578600	4049414	Oe/Oes	348	44
051110-3	11	578564	4049434	Oe	180	30
051110-5	11	578493	4049447	Oa	150	36
051110-5	11	578493	4049447	Oa	350	40
051110-7	11	578372	4049594	Oa	340	46
051110-8	11	578371	4049612	Oa	330	42
051110-9	11	578366	4049634	Oe	345	45
051110-12	11	578478	4049560	Oe	355	54
051110-13	11	578632	4049454	Oes	357	46
051210-2	11	578522	4049655	Oes	356	46
051210-3	11	578390	4049841	Oe/Oes	230	39
051210-4	11	578344	4049851	Oes	320	56
051210-6	11	578311	4049822	Oe	340	47
051210-7	11	578298	4049809	Oe	332	61
051210-8	11	578285	4049798	Oe	335	34
051210-10	11	578099	4049744	Oa/Oe	005	58
051210-11	11	578043	4049792	Oa	342	40
051210-12	11	577992	4049916	Oa	000	40
051210-13	11	577964	4050040	Oa	350	38
051210-15	11	577961	4050159	Oa	002	42
051210-16	11	577987	4050152	Oe	006	64
051310-2	11	571321	4056188	Cbba	268	44
051310-4	11	571418	4056088	Cbba	260	42
051310-6	11	571436	4056008	Cbpb	240	24
051310-7	11	571467	4055994	Cbpb	250	43
051310-10	11	571552	4055836	Cbpa	260	34
051310-15	11	571413	4055793	Cbpa	270	30
051310-16	11	571339	4055808	Cbpa	240	24
051310-17	11	571273	4055835	Cbpa	240	34
051310-19	11	571202	4055884	Cbpa	250	44
051310-23	11	571194	4055608	Cc	225	19
051310-24	11	571264	4055521	Cbpa	270	15
051310-25	11	571292	4055468	Cbpa	225	14
051310-26	11	571329	4055454	Cbpa	215	30
051310-29	11	571307	4055369	Cbpa	200	35

051310-33	11	571146	4055304	Cbpa	305	30
051310-34	11	571093	4055227	Cbpa	265	36
051310-35	11	571045	4055215	Cbpa	300	20
121110-4	11	579849	4051433	Oa/Oe	324	26
121110-7	11	580094	4051365	Oa/Oe	355	34
121110-8	11	580090	4051456	Oa	310	25
121110-16	11	580178	4051386	Oa	230	42
121110-20	11	580167	4051146	Oa	315	27
121110-21	11	580173	4051125	Cn?	297	40
121110-22	11	580116	4051097	Cn?	305	30
121210-1	11	579347	4051738	Oe	315	47
121210-3	11	579106	4052696	Oes	015	49
121210-7	11	577631	4052514	Oa	020	40
121210-8	11	577592	4052498	Oa	020	26
121210-9	11	577569	4052498	Oa	325	40
121210-10	11	577496	4052533	Oe	345	44
121210-12	11	577426	4052598	Sdl	310	22
121210-13	11	577398	4052652	Dnu	030	32
121210-15	11	577376	4052719	Og?	350	44
121210-16	11	577410	4052780	Oe	319	48
121210-19	11	577372	4052930	Oa	020	50
121210-20	11	577407	4053051	Oa	095	90
121510-1	11	576986	4048714	Og?	320	37
121510-2	11	577018	4048690	Og/On	322	36
121510-4	11	577029	4048689	Og?	320	33
121510-6	11	577112	4048746	Og?	300	15
121510-7	11	577158	4048809	Og?	010	15
121510-8	11	577218	4048802	On	345	38
121510-9	11	577229	4048814	On/Oa	005	39
121510-10	11	577242	4048819	Oa	003	27
121510-12	11	577294	4048841	Oa	355	40
121510-13	11	577308	4048861	Oa	340	41
121510-14	11	577317	4048881	Oa	000	21
121510-15	11	577344	4048888	Oa	355	21
121510-16	11	577372	4048853	Oa	340	25
121510-17	11	577383	4048843	Oa	330	16
121510-18	11	577403	4048824	Oa	150	15
121510-20	11	577438	4048770	Oa	345	35
121510-21	11	577441	4048744	Oa	022	26
121510-22	11	577432	4048686	Oa	015	25
121510-23	11	577358	4048664	Oa	000	13
121510-24	11	577295	4048626	Oa	012	24
121610-5	11	578523	4049519	Oe	345	54
121610-7	11	578479	4049557	Oe	350	50
121610-9	11	578464	4049602	Oe	345	49
121610-12	11	578299	4049662	Oa	355	50
121610-13	11	578195	4049437	Oa	340	36
121610-14	11	578271	4049382	Oa	354	39
121610-15	11	578219	4049310	Oa	350	40
121610-18	11	578396	4049150	Oa	350	33

121610-19	11	578434	4049124	Oa	357	30
121610-20	11	578459	4049110	Oa	350	60
121610-22	11	578488	4049165	Oa/Oe	353	51
121710-2	11	579200	4051251	Dsdu	320	34
121710-4	11	579296	4051198	Dsdu	312	34
121710-5	11	579240	4051279	Dsdu	330	30
121710-8	11	579173	4051559	Dsdu	300	55
121710-9	11	579188	4051583	Dsdu	306	60
121710-2	11	579200	4051251	Dsdu	320	34
121710-4	11	579296	4051198	Dsdu	312	34
121710-5	11	579240	4051279	Dsdu	330	30
121710-8	11	579173	4051559	Dsdu	300	55
121710-9	11	579188	4051583	Dsdu	306	60
121710-10	11	579196	4051657	Dsdu	305	60
121710-12	11	579327	4051738	Oe	320	45

APPENDIX B

Table 4. Fracture data with waypoint location numbers and corresponding lithology. For lithologic abbreviations seen Plate 1. All UTM data was measured in NAD 1927 and then reprojected in ArcMap in NAD 1983.

WAYPOINT	ZONE	EASTING	NORTHING	LITHOLOGY	FRACTURES	
					STRIKE	DIP
010410-1	11	562236	4057872	Cbb	135	80
010410-4	11	561954	4057690	Cbb	180	62
010510-1	11	558672	4055805	Cz	080	75
010510-2	11	559029	4056106	Cc	104	53
010510-3	11	559058	4056074	Cc	275	66
010610-1	11	559194	4055299	Cpcw	282	90
010610-2	11	559232	4055322	Cpcw	080	80
010610-3	11	559281	4055434	Cpcw	180	60
010610-4	11	559273	4055414	Cpcw	215	45
010610-5	11	559231	4055371	Cpcw	080	64
010610-6	11	559229	4055607	Cpcw	244	11
010610-7	11	558424	4056261	Cbp	355	65
010610-9	11	558454	4056336	Cbp	266	72
010610-10	11	558483	4056360	Cbp	068	88
010610-11	11	558535	4056186	Cbp	268	76
010710-1	11	559915	4056152	Cc	160	87
010710-2	11	559854	4056292	Cc	110	17
010710-3	11	559912	4056371	Cc	085	72
010710-4	11	560159	4056493	Cbp	031	86
010710-5	11	560091	4057302	Cbb	270	70
010710-6	11	560493	4057630	Cbb	075	90
010810-1	11	561769	4057604	Cbb	290	90
010810-3	11	561635	4057931	Cbb	281	47
010810-4	11	561828	4058231	Cn	089	57
010810-5	11	561821	4058361	Cn	250	58
010810-6	11	563164	4056524	Cc	170	34
010810-7	11	563228	4056046	Cbp	133	90
010910-2	11	563915	4053608	Cbp	191	59
010910-3	11	564103	4053839	Cbb	280	19
010910-4	11	564225	4054047	Cbb	208	5
010910-5	11	564322	4053209	Cbb	350	90
011310-6	11	579209	4051079	Dsdu?	230	89
011310-7	11	579031	4051227	Dsdu?	055	73
011310-9	11	578986	4051348	Dsdu?	093	71
011410-3	11	566924	4052443	Cc	307	85
011510-2	11	570694	4055938	Cbpb	345	90
011510-2	11	570694	4055938	Cbpb	060	90
011510-2	11	570694	4055938	Cbpb	160	80

011510-4	11	568336	4053376	Cc	045	90
011510-11	11	568213	4053688	Cc	236	83
011610-1	11	565324	4053902	Cbpa	345	50
011710-4	11	564989	4053935	Cc	105	60
011710-8	11	564921	4054023	Cpcw	185	66
011810-1	11	569755	4055793	Cc	350	81
011810-3	11	569699	4055841	Cpcw	332	70
011810-4	11	569572	4056229	Cc	340	85
031610-7	11	569982	4056433	Cc	345	78
031610-8	11	570054	4056480	Cbpa	343	90
031610-13	11	570229	4056773	Cbpa	355	62
031610-14	11	570169	4056074	Cc	030	90
031610-17	11	570137	4056009	Cbpa	347	65
031610-19	11	570124	4055980	cbpa	167	80
031710-1	11	573271	4054363	Oes	200	87
031710-3	11	573283	4054268	Oes	055	67
031710-5	11	573643	4054230		310	65
031710-6	11	573715	4054250	Oa	130	89
031710-10	11	573814	4054316	Oa	090	90
031710-11	11	573868	4054347		340	56
031710-16	11	573614	4053890	Sdm	040	39
031810-1	11	569855	4054896	Cz	270	83
031810-4	11	569653	4054910	CPCW	323	90
031810-5	11	569498	4055060	Cz	349	90
031810-8	11	569410	4055042	Cz	080	57
031810-9	11	569338	4055128	Cz	100	67
031810-10	11	569333	4055148	Cz	166	86
031810-11	11	569176	4055170	Cz	053	78
031810-14	11	569116	4054897	Cz	071	65
031910-9	11	568614	4054649	Cz	145	84
031910-16	11	568022	4053993	Cbpb	148	70
031910-19	11	568123	4053774	Cbpa	140	67
031910-21	11	568041	4053671	CC	065	55
032010-1	11	568780	405800	Cc	160	73
032010-13	11	568936	4055554	Cpcw	160	90
032310-6	11	570572	4057590	Cbb	242	38
032310-7	11	570812	4057567	Cbb	315	90
032510-3	11	571216	4053558	Oe	300	45
032510-4	11	571225	4053517	Oe	180	90
032510-5	11	571207	4053423	Oe	310	75
032510-12	11	570887	4053177	Oa	240	90
032510-13	11	570923	4053156	Oe	235	89
032510-14	11	570860	4053398	Oe	060	50
032610-5	11	570240	4052288	Oa	080	75
032610-7	11	570024	4052214	Oa	085	55
032610-8	11	569882	4052206	Oe	190	90
032610-10	11	569849	4052136	Oe	085	90
032610-20	11	571240	4054773	Cc	220	90
042610-3	11	564577	4055131	Cbb	330	70
042610-14	11	564692	4054772	Cbb	285	70

042610-20	11	564246	4054523	Cbb	235	29
042710-6	11	564784	4052454	Sz	115	76
042710-14	11	565071	4054547	Cbb	190	44
042710-15	11	565058	4054579	Cbb	332	5
042710-18	11	564810	4054218	Cbb	359	28
042810-2	11	569901	4051945	Oe	032	90
042810-5	11	569843	4051799	Oe	008	81
042810-6	11	569766	4051986	Oe	305	84
042810-7	11	569843	4051745	Oe	300	85
042810-8	11	569910	4051582	Oe	280	74
042810-10	11	569920	4051631	Oe	254	79
042810-11	11	569978	4051724	Oe	005	70
042810-12	11	570015	4051760	Oe	300	22
042810-15	11	570077	4051804	Oes	335	80
042810-17	11	570153	4051763	Oes	262	81
042810-23	11	570083	4051634	Oe	098	83
042810-24	11	570171	4051501	Oe	230	66
042810-26	11	570105	4051399	Oe	337	84
042910-4	11	570910	4051177	Oa	279	80
042910-5	11	570971	4051202	Oa	115	64
042910-9	11	571329	4051320	Oa	319	88
042910-14	11	571543	4051426	Oe	340	46
042910-17	11	571393	4051477	Oe	016	69
042910-19	11	571075	4051172	Oa	353	25
043010-3	11	564460	4051921	Sz	057	54
043010-4	11	564390	4051841	Sz	305	90
043010-5	11	564130	4051887	Sz	017	69
050110-2	11	566678	4054577	Cbpc	060	77
050110-3	11	566818	4054530	Cbbc	143	81
050110-14	11	566970	4054202	Cbbc	290	83
050110-15	11	567269	4054249	Cbbb	040	57
050110-19	11	567130	4054121	Cbbc	319	79
050210-5	11	567110	4053889	Cbpc	326	82
050210-6	11	567229	4053899	Cbpc	120	85
050210-7	11	567218	4053875	Cbpc	349	85
050210-15	11	567120	4053583	Cbpc	160	82
050210-19	11	567086	4053436	Cbpc	153	76
050210-28	11	566682	4053326	Cbpc	200	20
050810-2	11	578992	4052757	Oe/Oes	243	75
050810-7	11	578993	4052878	Oa/Oe	072	56
050810-12	11	579073	4052920	Oe	035	65
050810-13	11	579124	4052988	Oes	247	90
050810-29	11	578413	4051552	Dsdu	225	84
050910-2	11	579328	4050721	Oe	265	63
050910-6	11	579444	4051104	Dsdu	070	68
050910-7	11	579505	4051125	Dsdu	085	65
050910-25	11	579938	4051253	Oa	215	71
051010-4	11	572874	4054216	Oes	086	43
051010-6	11	572906	4054124	Oes	053	74
051010-8	11	573011	4054069	Oes	337	63

051010-10	11	573067	4054299	Oes/dsdu	095	42
051010-13	11	572984	4054362	Oes	240	43
051110-1	11	578609	4049291	Oe	350	42
051110-2	11	578600	4049414	Oe/Oes	243	74
051110-3	11	578564	4049434	Oe	285	79
051110-4	11	578512	4049442	Oe	090	75
051110-5	11	578493	4049447	Oa	100	60
051110-6	11	578446	4049466	Oa	270	75
051110-9	11	578366	4049634	Oe	217	45
051110-10	11	578372	4049676	Oe	255	66
051110-11	11	578452	4049655	Oe	193	47
051210-1	11	578566	4049610	Oe	063	28
051210-5	11	578314	4049849	Oe	165	90
051210-7	11	578298	4049809	Oe	250	45
051210-8	11	578285	4049798	Oe	068	85
051210-9	11	578139	4049749	Oe	145	51
051210-10	11	578099	4049744	Oa/Oe	090	79
051210-14	11	577998	4050079	Oe	145	55
051210-15	11	577961	4050159	Oa	200	54
051210-16	11	577987	4050152	Oe	257	64
051210-17	11	578056	4050171	Oe	315	75
051210-20	11	578051	4050348	Oe	225	42
051310-3	11	571399	4056170	Cbba	163	90
051310-6	11	571436	4056008	Cbpb	137	56
051310-7	11	571467	4055994	Cbpb	035	68
051310-9	11	571519	4055902	Cbpa	160	90
051310-10	11	571552	4055836	Cbpa	025	74
051310-12	11	571493	4055799	Cbpa	055	52
051310-15	11	571413	4055793	Cbpa	115	69
051310-17	11	571273	4055835	Cbpa	135	85
051310-24	11	571264	4055521	Cbpa	060	78
051310-25	11	571292	4055468	Cbpa	055	76
051310-30	11	571279	4055344	Cbpa	050	90
051310-31	11	571250	4055339	Cbpa	240	85
051310-32	11	571229	4055316	Cbpa	305	90
051310-34	11	571093	4055227	Cbpa	180	82
121510-21	11	577441	4048744	Oa	215	55
121610-17	11	578347	4049174	Oa	174	57
BKCPCW	11	565299	4053918	Cpcw	075	63
BKCPCW	11	565299	4053918	Cpcw	315	80

APPENDIX C

Table 5. Secondary fracture data with waypoint, location numbers and corresponding lithology. For lithologic abbreviations see Plate 1. All UTM data was measured in NAD 1927 and then reprojected in ArcMap in NAD 1983.

WAYPOINT	ZONE	EASTING	NORTHING	LITHOLOGY	FRACTURES		SECONDARY	
					STRIKE	DIP	STRIKE	DIP
010510-2	11	559029	4056106	Cc	104	53	193	88
010610-1	11	559194	4055299	Cpcw	282	90	075	03
010610-5	11	559231	4055371	Cpcw	080	64	147	88
010610-6	11	559229	4055607	Cpcw	244	11	166	71
010610-7	11	558424	4056261	Cbp	355	65	080	45
010710-3	11	559912	4056371	Cc	085	72	003	89
010710-4	11	560159	4056493	Cbp	031	86	113	34
010710-5	11	560091	4057302	Cbb	270	70	016	53
010810-1	11	561769	4057604	Cbb	290	90	188	90
010810-5	11	561821	4058361	Cn	250	58	130	78
010910-2	11	563915	4053608	Cbp	191	59	024	56
010910-3	11	564103	4053839	Cbb	280	19	019	75
010910-4	11	564225	4054047	Cbb	208	5	018	90
010910-5	11	564322	4053209	Cbb	350	90	248	58
011810-1	11	569755	4055793	Cc	350	81	085	52
031610-19	11	570124	4055980	cbpa	167	80	255	51
031710-3	11	573283	4054268	Oes	055	67	145	66
031810-5	11	569498	4055060	Cz	349	90	105	63
031810-10	11	569333	4055148	Cz	166	86	080	75
031810-11	11	569176	4055170	Cz	053	78	335	84
031810-14	11	569116	4054897	Cz	071	65	244	29
031910-19	11	568123	4053774	Cbpa	140	67	045	59
032010-1	11	568780	405800	Cc	160	73	250	79
032310-7	11	570812	4057567	Cbb	315	90	225	90
032510-5	11	571207	4053423	Oe	310	75	240	82
032510-12	11	570887	4053177	Oa	240	90	180	90
032510-13	11	570923	4053156	Oe	235	89	200	84
032610-7	11	570024	4052214	Oa	085	55	275	62
032610-8	11	569882	4052206	Oe	190	90	050	90
032610-10	11	569849	4052136	Oe	085	90	165	90
042710-6	11	564784	4052454	Sz	115	76	045	43
042710-15	11	565058	4054579	Cbb	332	5	230	90
042810-5	11	569843	4051799	Oe	008	81	290	76
042810-6	11	569766	4051986	Oe	305	84	006	90
042810-7	11	569843	4051745	Oe	300	85	010	90
042810-10	11	569920	4051631	Oe	254	79	027	79

042810-12	11	570015	4051760	Oe	300	22	040	76
042810-23	11	570083	4051634	Oe	098	83	072	68
042810-24	11	570171	4051501	Oe	230	66	075	61
042810-26	11	570105	4051399	Oe	337	84	020	81
042910-9	11	571329	4051320	Oa	319	88	052	74
042910-14	11	571543	4051426	Oe	340	46	230	90
042910-17	11	571393	4051477	Oe	016	69	110	72
043010-3	11	564460	4051921	Sz	057	54	330	87
050110-3	11	566818	4054530	Cbbc	143	81	350	86
050110-15	11	567269	4054249	Cbbb	040	57	230	22
050210-5	11	567110	4053889	Cbpc	326	82	062	38
050210-15	11	567120	4053583	Cbpc	**160**	**82**	060	40
050910-7	11	579505	4051125	Dsdu	085	65	195	75
051110-1	11	578609	4049291	Oe	350	42	155	38
051110-4	11	578512	4049442	Oe	090	75	235	65
051110-5	11	578493	4049447	Oa	100	60	068	55
051110-6	11	578446	4049466	Oa	270	75	213	67
051110-9	11	578366	4049634	Oe	217	45	235	85
051110-10	11	578372	4049676	Oe	255	66	180	34
051110-11	11	578452	4049655	Oe	193	47	240	70
051210-5	11	578314	4049849	Oe	165	90	246	90
051210-9	11	578139	4049749	Oe	145	51	055	85
051210-10	11	578099	4049744	Oa/Oe	090	79	215	56
051210-14	11	577998	4050079	Oe	145	55	340	79
051210-20	11	578051	4050348	Oe	225	42	338	60
051310-6	11	571436	4056008	Cbpb	137	56	050	65
051310-7	11	571467	4055994	Cbpb	035	68	174	78
051310-9	11	571519	4055902	Cbpa	160	90	085	70
051310-10	11	571552	4055836	Cbpa	025	74	056	70
051310-12	11	571493	4055799	Cbpa	055	52	335	65
051310-17	11	571273	4055835	Cbpa	135	85	197	87
051310-24	11	571264	4055521	Cbpa	060	78	155	70
051310-25	11	571292	4055468	Cbpa	055	76	145	84
051310-31	11	571250	4055339	Cbpa	240	85	120	75
051310-34	11	571093	4055227	Cbpa	180	82	145	77

APPENDIX D

Table 6. Foliation data with corresponding bedding measurements where both were measureable with waypoint, location numbers, and corresponding lithology. All UTM data was measured in NAD 1927 and then reprojected in ArcMap in NAD 1983.

WAYPOINT	ZONE	EASTING	NORTHING	LITHOLOGY	BEDDING		FOLIATION	
					STRIKE	DIP	STRIKE	DIP
032010-5	11	568903	4055394	Cpcw	285	27	285	46
032410-4	11	568454	4055087	Cc			65	78
032410-5	11	568506	4055159	Cc			320	81
032610-21	11	571323	4054899	Cc			243	60
032810-9	11	566831	4052713	Cpcw			270	54
032810-11	11	566828	4052683	Cpcw			260	40
032810-24	11	566935	4052286	Cc			350	54
032910-16	11	567339	4053170	Cc	200	10	200	10
032910-17	11	567396	4053185	Cc	230	50	230	20
050910-16	11	580009	4051529	Oe	305	20	254	85
051010-13	11	572984	4054362	Oes			195	90
121210-7	11	577631	4052514	Oa	020	40	335	24
121210-9	11	577569	4052498	Oa	325	40	210	57
121510-12	11	577294	4048841	Oa	355	40	310	28
121510-17	11	577383	4048843	Oa	330	16	300	35
121510-23	11	577358	4048664	Oa	000	13	310	25

APPENDIX E

Table 7. Field photos with waypoint numbers, location, and corresponding lithology. Each photo number is hyperlinked to the photo found at that location. Data was recorded in NAD 1927.

WAYPOINT	ZONE	EASTING	NORTHING	LITHOLOGY	PHOTO #					
010710-4	11	560159	4056493	Cbp	144-5033	5034				
010710-6	11	560493	4057630	Cbb	144-5035					
010810-2	11	561729	4057679	Cbb	144-5036					
010810-3	11	561635	4057931	Cbb	144-5037					
010810-5	11	561821	4058361	Cn	144-5038					
010910-1	11	563556	4053723	Cbp	144-5039					
010910-3	11	564103	4053839	Cbb	144-5041					
010910-5	11	564322	4053209	Cbb	144-5043					
011010-11	11	564365	4053466	CPCW	144-5046	5047				
011010-4	11	563753	4053383	Cbb	144-5044	5045				
011210-3	11	570811	4049382	Dsdu?	144-5054					
011210-3	11	570811	4049382	Dsdu?	144-5053					
011210-3	11	570811	4049382	Dsdu?	144-5051					
011210-3	11	570811	4049382	Dsdu?	144-5050					
011210-4	11	570784	4049493	Dsdu?	144-5055					
011210-5	11	570766	4049715	Dsdu?	144-5056					
011210-6	11	570805	4049740	Dsdu?	144-5057					
011310-1	11	579094	4050645	Dsdu?	144-5077	5078	5079	5080	5081	5082
011310-2	11	579133	4050752	Dsdu?	144-5087	5088				
011310-4	11	579099	4051051	Dsdu?	144-5094					
011310-4	11	579099	4051051	Dsdu?	144-5093					
011310-6	11	579209	4051079	Dsdu?	144-5095					
011310-9	11	578986	4051348	Dsdu?	144-5100	5101	5102	5103		
011410-2	11	566878	4052390	bk	144-5111					
011410-3	11	566924	4052443	bk	144-5112	5113				
011510-10	11	568208	4053598	Cbpa	37 & 38					
011510-10	11	568208	4053598	Cbpa	144-5134	5135	5136			

011510-3	11	570650	4056003	Bk	144-5121						
011510-5	11	568316	4053428	Cbpa	144-5123						
011510-5	11	568316	4053428	Cbpa	144-5122						
011510-6	11	568318	4053448	cbpa	144-5125						
011510-8	11	568236	4053563	Cbpa	144-5126						
011610-1	11	565324	4053902	Cbpa	144-5040						
011710-1	11	563768	4053061		144-5041						
011710-2	11	564979	4053922		144-5144						
011710-2	11	564979	4053922		144-5143						
011710-9	11	564896	4054032	CPCW	144-5149						
011810-12	11	569379	4054016	CPCW	144-5159	5160	5161	5162	5163		
011810-13	11	569341	4053959	CPCW	144-5164	5165					
011810-6	11	569543	4056312	Cc	144-5154						
011810-7	11	569501	4056299	Cc	144-5157						
011810-9	11	569529	4056250	Cc	144-5158						
031510-3	11	562502	4054524	Cbpc	144-5218						
031610-11	11	570220	4056527		144-5232						
031610-5	11	569803	4056544		144-5221						
031610-6	11	569782	4056553		144-5222						
031610-7	11	569982	4056433	Cc	144-5223	5224	5225	5226			
031610-8	11	570054	4056480	Cbpa	144-5227	5228	5229	5230			
031610-9	11	570167	4056478	Cc	144-5231						
031710-12	11	573672	4054157	Oa	144-5243						
031710-16	11	573614	4053890	Sdm	144-5246	5247	5248	5249	5250	5251	5252
031710-2	11	573277	4054326	Dsdu?	144-5234	5235	5236	5237	5238		
031710-5	11	573643	4054230		144-5239	5240					
031710-8	11	573764	4054285	Dsdu?	144-5241						
031810-10	11	569333	4055148	Cz	144-5262						
031810-11	11	569176	4055170	Cz	144-5263						
031810-12	11	569146	4055168	Cz	144-5264						
031810-16	11	569057	4054688	Cz	144-5265						
031810-17	11	569060	4054643	CPCW	144-5266	5267	5268				
031810-3	11	569760	4054772	Cz	144-5253	5254					
031810-6	11	569435	4055038	Cz	144-5255						
031810-7	11	569426	4055036	Cz	144-5256	5257	5258				
031810-8	11	569410	4055042	Cz	144-5259	5260	5261				

031910-11	11	567979	4054056	BK	144-5274					
031910-14	11	568022	4053969	cbpa	144-5275	5276	5277			
031910-16	11	568022	4053993	cbpa	144-5278					
031910-17	11	568064	4053991	CC	144-5279	5280				
031910-18	11	568056	4053954	BK	144-5281					
031910-20	11	568133	4053744	Cc	144-5282	5283	5284			
031910-3	11	568876	4054501	CC	144-5269					
031910-4	11	568795	4054453	CC	144-5270	5271				
031910-5	11	568764	4054442	CC	144-5272					
031910-6	11	568735	4054460	CPCW	144-5273					
032010-16	11	568998	4055652	BK	144-5294					
032010-20	11	568866	4055791	Cc	144-5295					
032210-10	11	567528	4054817	Cbb	144-5303	5304				
032210-2	11	567983	4054417	Cbb	144-5296	5297	5298			
032210-4	11	567844	4054559	Cbb	144--5299	5300				
032210-9	11	567539	4054791	Cbb	144-5302					
032410-11	11	568305	4055207	Cc	144-5314					
032410-13	11	568097	4055194	Cc	144-5315					
032410-17	11	568528	4055511	Cc	144-5316	5317				
032410-18	11	568743	4055783	Cc	144-5318					
032410-4	11	568454	4055087	Cc	144-5308					
032410-5	11	568506	4055159	Cc	144-5309					
032410-8	11	568441	4055200	BK	144-5310	5311	5312			
032410-9	11	568359	4055174	Bk	144-5313					
032510-8	11	570727	4053324	Dsdu?	144-5319					
032610-18	11	571057	4054676	Cc	144-5321					
032610-19	11	571131	4054715	Cns	144-5322					
032610-22	11	571324	4054923	Cc	144-5323	5324	5325	5326		
032610-23	11	571051	4054633	Cc	144-5327	5328				
032610-8	11	569882	4052206	Oe	144-5320					
032710-18	11	574504	4055211	CPCW	144-5332	5333	5334	5335	5336	5337
032710-5	11	571612	4055133	Cc	144-5329					
032810-13	11	566898	4052677	Cc	144-5342	5343	5344			
032810-16	11	567151	4052671	cbpa	144-5345					
032810-17	11	567186	4052702	Cc	144-5346					
032810-19	11	567196	4052655	Cc	144-5348	5349				

032910-14	11	567297	4053096	Cc	144-5358		
032910-15	11	567296	4053122	Cc	144-5359		
032910-16	11	567339	4053170	Cc	144-5360	5361	
032910-17	11	567396	4053185	Cc	144-5362		
032910-19	11	567639	4052991	Cc	144-5366		
032910-2	11	567291	4052344	Cbpa	144-5353		
032910-20	11	567916	4053318	Cc	144-5367	5368	
032910-5	11	567385	4052496	Cc	144-5354		
032910-7	11	567412	4052567	Cc	144-5355		
042610-4	11	564596	4055123	Cbb	144-5369		
042610-5	11	564617	4055087	Cbb	144-5370	5374	5375
042610-8	11	564781	4054993	Cbb	144-5377		
042710-11	11	565327	4054690	bk	144-5390		
042710-12	11	565227	4054653	bk	144-5391		
042710-14	11	565071	4054547	bk	144-5397	5398	5399
042710-23	11	564904	4053796	cz	144-5405		
042710-3	11	564308	4052562	cc	144-5382	5383	
042710-4	11	564408	4052580	cpcw	144-5384	5385	5386
042710-7	11	564775	4052298	Sz	144-5387		
042810-13	11	570033	4051797	Oe	144-5406		
042810-14	11	570043	4051807	Oe/Oes	144-5407		
042810-15	11	570077	4051804	Oes	144-5408		
042810-16	11	570136	4051766	Oes	144-5409		
042910-10	11	571426	4051398	Oe	144-5423		
042910-11	11	571496	4051398	Oe	144-5429		
042910-17	11	571393	4051477	Oe	144-5430		
042910-19	11	571075	4051172	Oa	144-5435	5436	5437
042910-6	11	571021	4051219	Oa	144-5421	5422	
042910-7	11	571209	4051195	Oa	144-5422		
043010-11	11	565095	4051644	sz	144-5442		
043010-8	11	564694	4051278	cpcw	144-5438		
050110-10	11	566970	4054349	cbbc	144-5447		
050110-13	11	566883	4054164	cbbb	144-5450		
050110-21	11	567097	4054118	cbbc	144-5452		
050110-4	11	566869	4054527	cbbc	144-5443	5444	
050210-15	11	567120	4053583	bk	HPIM0531		

050310-10	11	566947	4053144	bk	144-5458			
050310-11	11	566914	4053078	bk	144-5459			
050310-15	11	566733	4052954	bk	144-5460			
050310-3	11	566515	4053065	bk	144-5454	5455		
050910-10	11	579690	4051226	Oa/Cn	144-5504	5505	5506	
050910-12	11	579694	4051338	Oa	144-5508			
050910-13	11	579706	4051402	Oa	144-5509	5510	5511	
050910-15	11	579849	4051430	Oe	144-5512			
050910-17	11	580136	4051474	Oe	144-5513			
050910-26	11	579935	4051371	Oa/Oe	144-5522	5523		
050910-9	11	579678	4051217	Dnu	144-5501	5502		
051010-10	11	573067	4054299	Oes/dsdu	144-5536	5537		
051010-12	11	573053	4054363	oes	144-5538			
051010-13	11	572984	4054362	Oes	144-5539	5540		
051010-14	11	572931	4054360	Oes	144-5541			
051010-3	11	572828	4054276		144-5527			
051010-3	11	572828	4054276		144-5526			
051010-4	11	572874	4054216		144-5529			
051010-7	11	572978	4054072	Oes/sdl	144-5530	5531	5532	5533
051010-8	11	573011	4054069	Oes	144-5534	5535		
051210-18	11	578064	4050222	Oe	144-5553			
051210-3	11	578390	4049841	Oe/Oes	144-5544	5545	5546	5547
051210-7	11	578298	4049809	Oe	144-5548			
051310-12	11	571493	4055799	cbpa	144-5560			
051310-13	11	571483	4055788	cbpa	144-5561	5562		
051310-32	11	571229	4055316	cbpa	144-5567			
121110-10	11	580209	4051465	Oa	144-5696			
121110-11	11	580209	4051547	Oe	144-5698-01			
121110-13	11	580248	4051563	Oa/Oe	144-5702			
121110-15	11	580240	4051486	Oa/Oe	144-5687			
121110-20	11	580167	4051146	Oa	144-5688			
121110-4	11	579849	4051433	Oa/Oe	144-5679			
121110-7	11	580094	4051365	Oa/Oe	144-5680	5681	5682	
121110-9	11	580156	4051420	Oa/Oe	144-5683	5684		
121210-10	11	577496	4052533	Oe	144-5696			
121210-11	11	577496	4052542	Oes	144-5698	5699	5700	5701

121210-13	11	577398	4052652	Dnu	144-5702			
121210-5	11	578557	4052823	Oe	144-5689			
121210-6	11	577677	4052531	breccia	144-5691			
121210-7	11	577631	4052514	Oa	144-5692	5693	5694	
121210-9	11	577569	4052498	Oa	144-5695			
121510-12	11	577294	4048841	Oa	144-5713	5714		
121510-14	11	577317	4048881	Oa	144-5715			
121510-15	11	577344	4048888	Oa	144-5717			
121510-17	11	577383	4048843	Oa	144-5719	5720	5721	5722
121510-18	11	577403	4048824	Oa	144-5723			
121510-21	11	577441	4048744	Oa	144-5729			
121510-22	11	577432	4048686	Oa	144-5730			
121510-4	11	577029	4048689	Og?	144-5711			
121510-8	11	577218	4048802	On	144-5712			
121610-10	11	578440	4049816	Oe/Oes	144-5747			
121610-12	11	578299	4049662	Oa	144-5757/58	144-5758		
121610-2	11	578652	4049213	Oe	144-5742			
121610-6	11	578507	4049518	Oe	144-5745			

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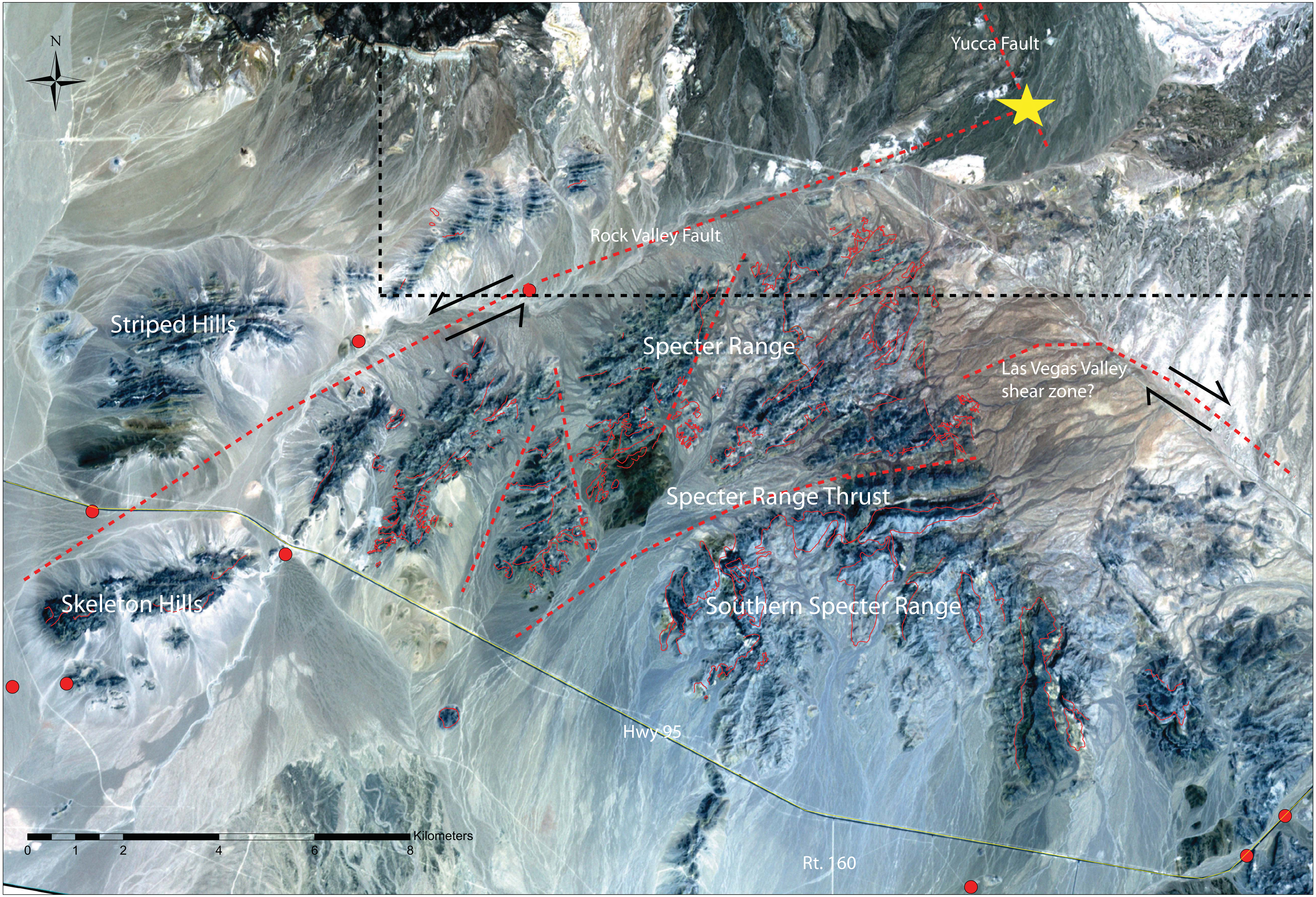
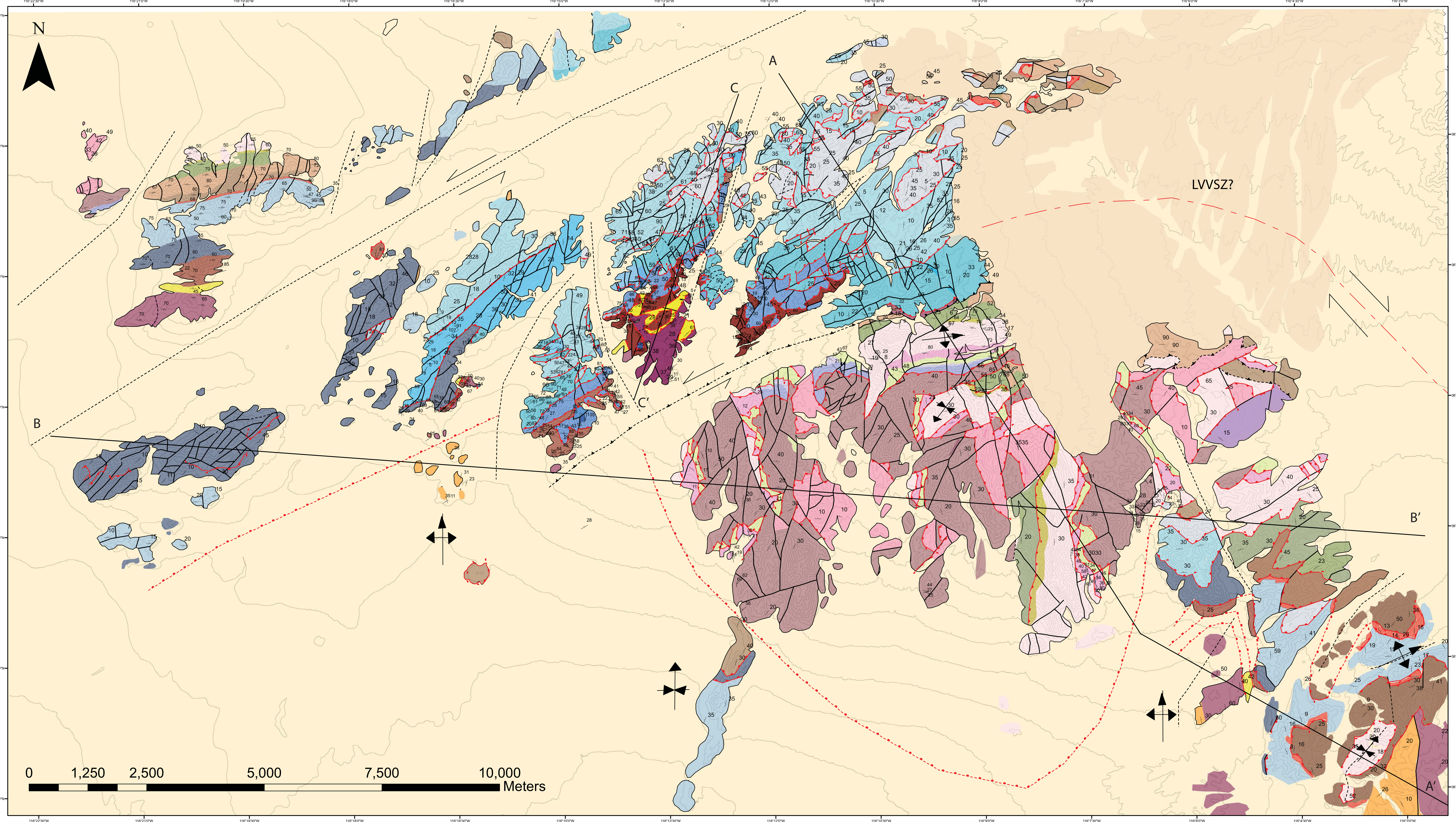


ASTER satellite imagery in the of the area of Plate 1. Map is projected in UTM NAD 1983 Zone 11 N.

Detachments
Faults
NTS Boundary
Nye County Propsed pizeo wells
Proximal location of suggested well



Base map was produced using the National Elevation Dataset (NED) from the USGS seamless downloadable maps. Contour intervals are in meters with an interval of 10m. All data is projected in NAD 83 Zone 11 N.

Explanation

- Detachments
- Inferred Detachments
- Thrust Faults
- Inferred Thrust Faults
- Normal Faults
- Inferred Normal Faults
- Bedding
- Overturned Bedding
- Anticline with plunge direction
- Syncline with plunge direction

List of Map Units

- Quaternary Alluvium
- Horse Springs Formation (Oligocene)
- Tertiary Limestones (Pliocene-Miocene)
- Devils Gate Limestone (Devonian)
- Nevada Formation (Devonian)
- Middle Silurian Dolomite (Silurian) — Dsdu: Undifferentiated Silurian Dolomite
- Lower Silurian Dolomite (Silurian)
- Ely Springs Dolomite (Ordovician)
- Eureka Quartzite (Ordovician)
- Antelope Valley Formation (Ordovician)
- Ninemile Formation (Ordovician)
- Goodwin Limestone (Ordovician)
- Nopah Formation (Cambrian)
- Dunderberg Shale (Cambrian)
- Bonanza King Formation; Cbbc (Cambrian) — Cbb: Upper Undifferentiated Bonanza King (Banded Mountain member)
- Bonanza King Formation; Cbba/Cbbb (Cambrian)
- Bonanza King Formation; Cbpb/Cpbc (Cambrian) — Cbp: Lower Undifferentiated Bonanza King (Papoose Lake Member)
- Bonanza King Formation; Cbpa (Cambrian)
- Carrara Formation (Cambrian)
- Zabriskie Quartzite (Cambrian)
- Wood Canyon Formation (Precambrian-Cambrian)
- Stirling Quartzite (Precambrian)
- Johnnie Formation (Precambrian)

Description of Map Units

Tsl-Tertiary Limestone (Pliocene-Miocene?) Tan to brownish microcrystalline limestone and contains volcanic fragments.
Hsp-Horse Spring Formation (Oligocene (Sargent and Stewart, 1971)/Miocene? (Barnes et al. 1968)) Laminated to thick bedded dense limestone with minor amounts of siltstone, sandstone and tuff.
Qal- Quaternary Alluvium: Poorly sorted unconsolidated sand to cobble sized sediments.

Dvg-Devils Gate Limestone (Devonian) (300 m) Predominantly thick-bedded gray to blue-gray limestone. The base contains thick-bedded limestones interbedded with medium-bedded dolomites. The upper 30 m is white vitreous quartzite (Burchfiel, 1964)

Dnu-Nevada Formation (Devonian) (500 m) The lower 130 m is olive-gray medium bedded dolomite at the base and a coarse grained quartzite with minor dolomitic and silty interbeds in the upper 270 m contain alternating bands of light and dark gray dolomite (Burchfiel, 1964) most of which is heavily brecciated.

Dsdu-Upper Unit (275 m) Light-olive-gray to olive-gray; some medium-light-gray bands show faint laminae; finely to coarsely crystalline; thick- to very thick- bedded in upper half, massive in lower half (Burchfiel, 1964). Brecciation is typical throughout the entire unit.

Sdm-Middle Unit (170 m) Light- to medium-dark gray finely crystalline, laminated to thin bedded dolomite with common chert layers and lenses in upper and lower part; quartz rich siltstone constitutes the lower 15 m, light-gray to yellowish weathered dolomite comprises the upper part (Sargent and Stewart, 1971). Fossils are abundant throughout.

Sdl-Lower Unit (25 m) Light- to medium-olive-gray in upper park, dark- to dark-olive-gray in lower part; finely to coarsely crystalline, rare chert lenses in upper part; chert layers as thick as 2 inches with some chert lenses and nodules in basal few meters; laminated to thin bedded. Abundant recrystallized columnals and coral heads as much as 1 foot in diameter (Sargent and Stewart, 1971).

Oes-Ely Springs (Upper Ord) 140 m: Upper 20-25 m light-olive-gray, thin-to thick bedded, burrow-mottled, variably bioclastic, containing ooids, oncoids. Remaining ~120 m of the Ely Springs is medium-dark-gray, burrow-mottled, irregularly thin- to thick-bedded with common planar laminations. Quartz sand is common at the base and the top (Burchfiel, 1964; Stewart, 1971).

Oe-Eureka Quartzite (Mid Ord) 140 m: Light to moderate brown weathering, white to light brown, thin to thick bedded, fine to medium grained, rounded to subrounded, moderately well sorted quartzite and friable sandstone (Burchfiel, 1964). Lower 10 m is predominantly sandy dolomite (Sargent and Stewart, 1971). Contains tabular planar crossbeds and, less commonly trough crossbeds (Burchfiel, 1964). Cross beds about .5 m thick on average. Skolithus burrows. Detached from the underlying Antelope Valley. A well bedded outcrop is hard to find as it is typically intensely fractured or brecciated.

Pogonip (Mid Ord-Upper Cam)

Oa-Antelope Valley (345 m): medium- and dark-gray, finely to coarsely crystalline, in well-defined beds a few cm to a few m; thinly crinkled to curved laminae of pale-red and yellowish-gray silty limestone constitute about 10% of the formation. Abundant fossils. Straight and coiled cephlapods common in middle 120 m. Lower 120 m contain layers of nodular chert as thick as 6 inches. The total thickness is similar to the type section at Antelope Valley, however in the Specter Range the unit is locally much thinner. Ninemile detachment permeates into lower layers of the Antelope Valley.

On-Ninemile (60 m): pale-olive-gray and gayish-red laminatedto thin-bedded claystone; minor thin lenses of brownish-gray aphanitic to finely crystalline abundantly fossiliferous limestone; sparse chert. Forms slopes with thin ledges. At its type section at Ninemile Canyon in Eureka County, (Merriam, 1963) the unit is as thick as 150 m. Detachment at its base often causes the section of Ninemile to be missing.

Og- Goodwin (150 m): Medium- to light-gray, rusty-weathering; local red mottling; chert in siliceous limestone laminae in upper part and as nodules in lower part; locally dolomitic especially at base. The type section at Ninemile Canyon is nearly 550 m thick (Merriam, 1963), however thicknessnes measured in Eureka are approximately 200 m less and better representative of the units average thickness. However in the Specter Range it is still approximately 200 m less. Lower contact placed at base of thin-bedded dolomite.

Cn-Nopah (Upper Cam) (425 m): The lower 120 m is thin bedded silty and cherty limestone and dolomite. The beds are commonly crenulated. The upper 300 m has distinctive light and dark gray alternating striped of thick bedded limestone and dolomite (Burchfiel, 1964). In some places the alternating bands are heavily brecciated and thinned suggesting stratigraphic detachment so that the conspicuous stripes remain cohesive with internal brecciation.

Cnd-Dunderberg Shale (30 m): olive-gray to reddish-brown fissle shale interbedded with thin beds of gray fossiliferous limestone (Burchfiel, 1964). This unit is often missing in the stratigraphic section within the Specter Range and serves as the main unit for the Nopah detachment.

Bonanza King Formation (Upper and Mid Cambrian):
Banded Mountain Member:

Cbbc (160 m) Predominately limestone with minor amounts of dolomite. Light-gray to yellowish gray and silty laminae consititute the upper half. Beds are thin- to medium bedded in the lower half (Sargent and Stewart, 1971). This unit is also detached.

Cbbb (480 m) Predominately dolomite with minor amounts of limestone. Light- to dark- gray alternating stripes from .5-3 m thick is the units defining characteristic. Dolomite is laminated to thin bedded, with locally silty and cherty layers (Sargent and Stewart, 1971).

Cbba (90 m): limestone, silty limestone, and minor dolomite; upper 60 m is dark-gray cliff-forming silty limestone with very thin wavy bedding, becomes more silty downward. The lower 30 m is dominantly grayish-orange slope-forming silty laminated to very thin bedded limestone with decreasing amounts of silt and clay towards the base (Sargent and Stewart, 1971). This unit is detached from the Papoose Lake member along silty horizons near the base.

Bonanza King Formation (Upper and Mid Cambrian):
Papoose Lake Member:

Cbpc (275 m): dolomite and limestone, laminated to thick-bedded; dolomite is light gray to very pale orange, contains scattered chert nodules in uppermost 40m. Limestone is dark to medium gray; local silty interbeds and bleached units are interspersed throughout the unit(Sargent and Stewart, 1971). Base is locally brecciated with minor brecciation persisting throughout weak layers of the unit probably related to the detachment of the unit below it.

Cbpb (55 m): silty limestone and dolomite, pale-yellowish-orange, thin-bedded, forms slope; prominent silty horizons at top, middle and base of unit (Sargent and Stewart, 1971). Also detached from its base and through out silty horizons in the unit. Detachment likely permeates through the entire units to the next highest unit.

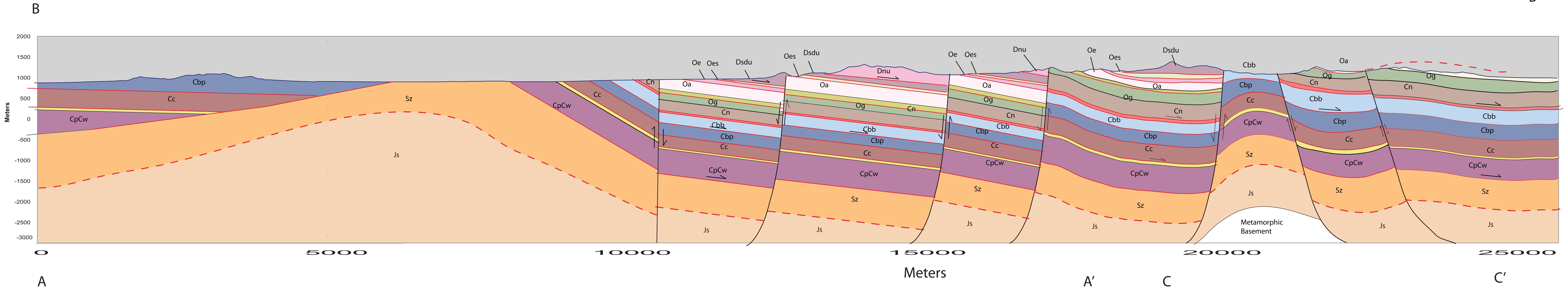
Cbpa (150 m): limestone, medium to dark gray with irregular discontinuous dolomitic mottling. Upper part generally contains 15-30 m of light gray bleached limestone (Sargent and Stewart, 1971). Contact is detached from the silty laminae of the underlying Carrara Formation.

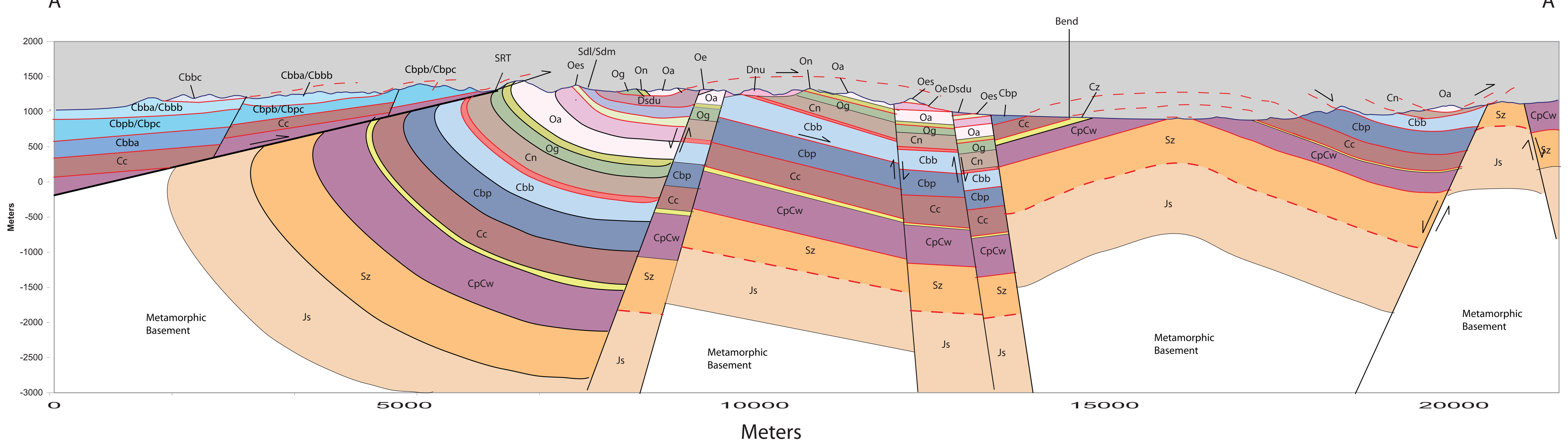
Cc-Carrara Formation (Mid and Lower Cambrian) (480 m)**:** Interbedded limestone, siltstone, sandstone, and shale in the lower two-thirds with fine grained mica rich sandstones and quartzites. Silty units decrease in abundance downward. Upper part is gray, platy limestone containing yellow- and red-weathering silt of clay partings (Sargent and Stewart, 1971). Its contact with the overlying Bonanza King is easily recognizable as the slope-forming, yellowish, silty limestone ends abruptly and massive cliff-forming gray carbonates of the Bonanza King begin.

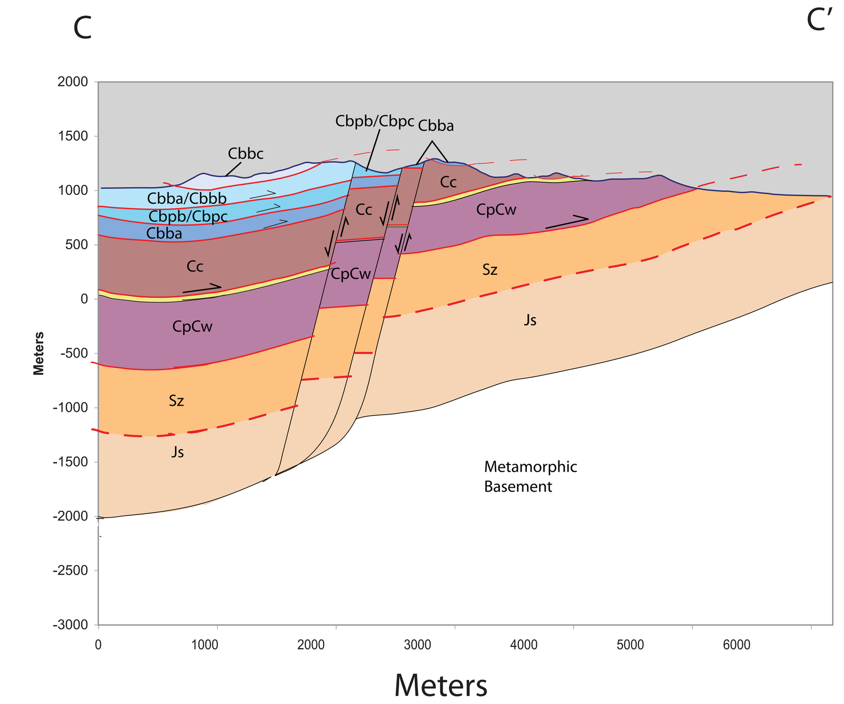
Cz-Zabriskie Quartzite (Cambrian) (50 m)**:** gray to pink, fine- to medium- grained, cross-laminated; contains some interbeds of olive-gray siltstone and shale; locally includes fine-grained micaceous standstone in upper part (Sargent and Stewart, 1971). The Zabriskie is often missing and almost always intensely fractured to brecciated. It is the principal detachment horizon from which the overly Carrara detaches.

CpCw-Wood Canyon (Late Proterozoic to Early Cambrian) (800 m)**:** Quartzite, sandstone, siltstone and shale. Slope forming rather than cliff forming Stirling. Top 7-8 meters is a thick ledge of white vitreous quartzite correlative with the Zabriskie (Burchfiel, 1964). Shaly and silty units increase in abundance in upper part of formation. Basal part of formation is tan weathering silty sandstone (Page et al., 2005). Likely detached from the Stirling Quartzite.

Sz-Stirling Quartzite (Late Pro) (900 m)**:** mostly purple, pink, maroon, gray, and white conglomeratic quartzite, quartzite sandstone, with minor beds of light to darn brown micaceous siltstone. Lower 20 m mostly white quartzite. Unit locally metamorphosed to low greenschist facies in northern Spring Mountains (Page et al., 2005).

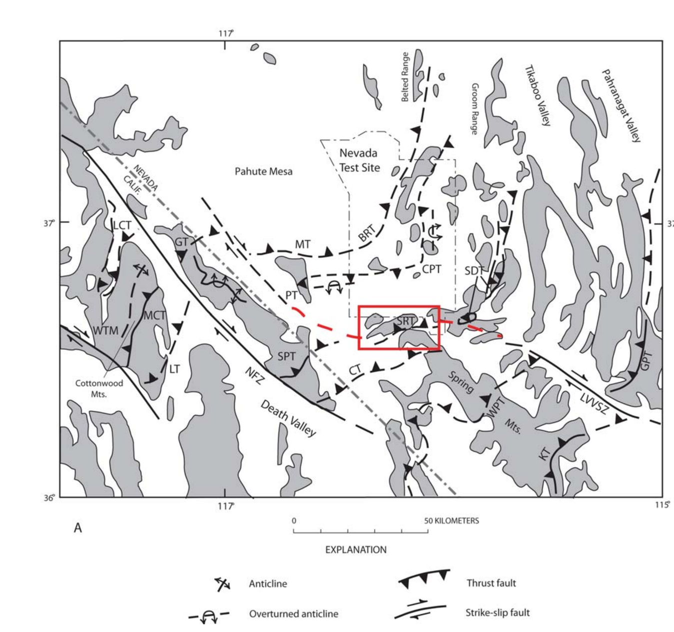




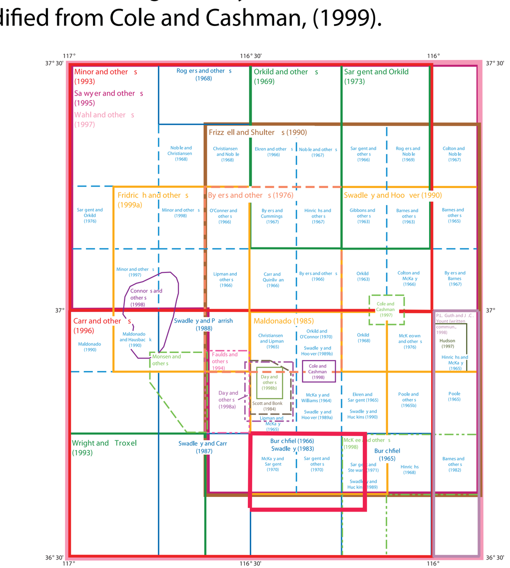


Cross Section Key

- Detachments
- Inferred Detachments
- Normal Faults
- Direction of motion



The red box denote the area of Plate 1 and Plate 2 and shows its location with respect to the Las Vegas Valley shear zone and Walker Lane domain. Figure modified from Cole and Cashman, (1999).



7.5 ' Quadrangle map of the Nevada test site from Slate et al., (1999). The area in the red box denotes the area of plate 1 and plate 2. 15' Quadrangle map from Burchfiel, 1965 was also used in map compilation.

Geologic Map of the Specter Range, Nye County, Nevada

Lindsay Williams, 2011

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