University of Nevada, Reno

Geology and Structure of Winters Creek, Jerritt Canyon District, Elko County, Nevada

A thesis submitted in partial fulfillment of the

requirements for the degree of Master of Science in

Geology

by

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December 2007

UMI Number: 1447627

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prepared under our supervision by

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Entitled

Geology and Structure of Winters Creek, Jerritt Canyon District, Elko County , Nevada

be accepted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE

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December, 2007

Abstract

The Winters Creek area is located in the Jerritt Canyon district within the northern Independence Range, Nevada. The district contains Carlin-type gold deposits characterized by submicroscopic gold hosted in autochthonous assemblage silty carbonates. At the Winters Creek open pit, ore is hosted in the autochthonous assemblage Roberts Mountains Formation. However, north of the deposit, are predominantly allochthonous, siliciclastic marine sediments, which were thrust over the autochthonous facies during the Devonian-Mississippian Antler Orogeny. A volcanic sequence comprised of ash-flow tuffs and volcanic sedimentary rocks, bearing Eocene fossil assemblages, is in depositional contact and, locally, fault contact with the allochthonous siliclastic sediments. With the exception of chalcedony flooding along the fault contact with the volcanic sequence, an alteration overprint was not evident. Though it is difficult to identify any soil geochemisty anomalies along structures, there are however, coincident soil anomalies north of the Winters Creek deposit that may suggest a potential target.

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Introduction

The Jerritt Canyon district, host to several Carlin-type gold deposits, is located in the northern Independence Range, about 45 miles, or 70 km, northwest of Elko, NV (Figure 1). The district was first prospected and mined in the early 1900s for stibnite and barite (Horton, 1962). Potential for gold mineralization was recognized by Hawkins (1973) and mining began in the 1980s. As of 2004, thirteen open pit mines and five underground mines have produced a total of 9.6 million ounces of gold at an average grade of 0.215 troy ounces/ton. By 2005, three underground mines were in production and remaining district resources were estimated to be 1,966,900 oz at a grade of 0.247 opt (Jones, 2005).

Exploration in the Winters Creek area began in the 1970s with reconnaissance mapping, soil, and rock chip sampling. Exploratory drilling programs were initiated in the early 1980's and by 1983 the area previously known as Deadman's Curve, now the Winters Creek orebody, had a defined resource of approximately 190,000 ounces. The orebody, shaped like a horseshoe, measured 610 m long and 215-460 m wide. In total, 1.2 Mt was mined at a grade of 0.149 opt (Bratland, 1991).

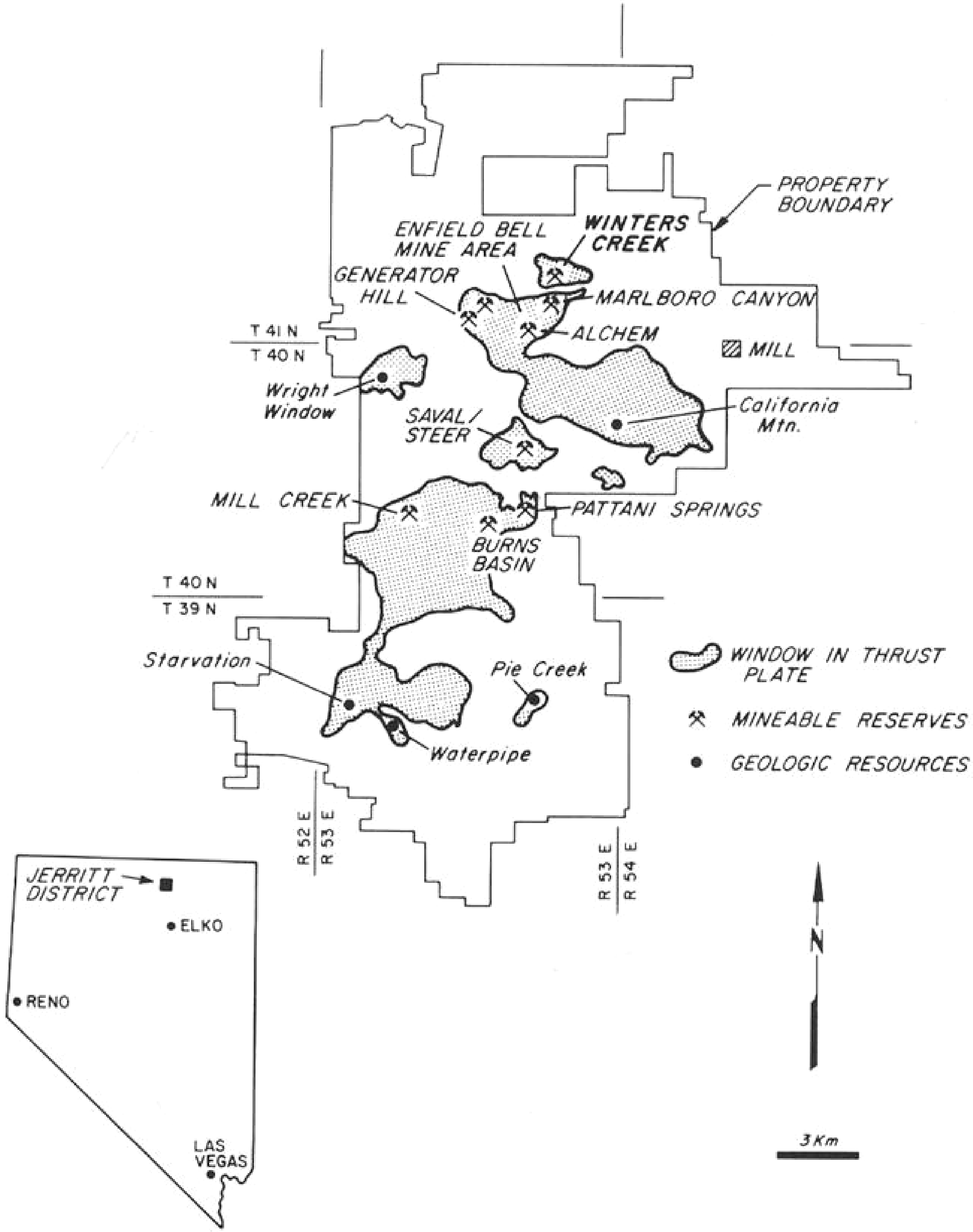

Figure 1. Location map of Winters Creek (from Bratland, 1991).

Previous Studies

In 1994, A. H. Hofstra published a PhD dissertation entitled, “Geology and Genesis of the Carlin-type Gold Deposits in the Jerritt Canyon District, Nevada.” The resulting genetic model proposed that meteoric waters rich in CO_2 and H_2S were circulating at high pressures and temperatures, scavenging gold from deep-seated rocks along the fluid flow path. Ore fluids traveled along high-angle structures, then traveled laterally in permeable rocks, depositing the gold. Mineralization was shown to be late Eocene in age.

Later work by Phinisey and others concentrated on identifying and characterizing igneous and hydrothermal events in the Jerritt Canyon District. Three hydrothermal events were recognized -- potassium metasomatism at approximately 320 Ma, sericitization at approximately 120 Ma, and an argillization and sulfidation event dated at a maximum age of 40.8 Ma -- as well as four igneous events (Phinisey *et al.,* 1996).

Dewitt (1999) completed a study on the SSX Mine, in particular examining alteration patterns, geochemical dispersion and controls on mineralization. The study concluded that there are two structural trends that localized ore at the SSX mine: older features striking from 290 to 310 degrees with an almost vertical dip and younger features striking from 190 to 230 degrees with dips from 60 to 80 degrees northwest. A study by Hutcherson (2000) at the Murray mine identified a northwest striking fault, the

New Deep Fault, as the principal ore control, further demonstrating the importance of northwest-striking features in localizing mineralization.

Previous studies that focused on the Winters Creek area include work by Bratland (1991), who analyzed the geology and controls on mineralization in the Winters Creek mine, and work by Leslie (1990), who examined the stratigraphy and age of the Snow Canyon Formation. Leslie divided the formation into a lower, a middle, and an upper unit. The lower unit is dominantly composed of chert and shale though it also contains greenstone. The middle unit is composed principally of quartzite while the upper unit is principally composed of chert and shale with minor greenstone.

Objective

The principal objective of this research is to better define the geology and structure in the Winters Creek area, focusing on the area just north of the Winters Creek gold deposit, and to assess the potential for additional gold mineralization. To achieve this, geologic mapping was conducted on digital orthophotos at a scale of 1 inch to 200 feet. This was supplemented by petrographic analysis.

Methods

Field work was carried out from June to August of 2005. Field maps were prepared at a scale of 1 inch to 200 feet on digital orthophotos which were provided by

Queenstake Resources Inc. Outcrop-style mapping was done when possible, however, as outcrop was rather sparse, much of the mapping was based on float. To document key features, photographs were taken. Representative rock samples were collected as well as rock samples with more unique characteristics.

Twenty-five of the rock samples were selected for petrographic analysis. Samples were cut into billets at the University of Nevada, Reno and were subsequently sent to Spectrum Petrographics Inc. for finishing. Petrographic analysis and photomicrography were completed at the University of Nevada, Reno on plane-polarized transmitted and reflected light microscopes.

In addition, Queenstake Resources Inc. provided soil geochemical data and drill hole data. The soil data was collected over many years by Queenstake Resources Inc. and compiled. Analytical procedures varied as the provided data were a compilation spanning many years. ALS Chemex laboratories provided 51 element analyses for some of the soils while Monitor Geochemical provided the analysis for the remaining soil samples.

Geologic Setting

In Nevada, the lower Paleozoic rocks are divided into three assemblages: the eastern, western, and transitional assemblages, referenced to the edge of the North American Continent as defined by the Sr-706 line. Each of the assemblages has different lithologies reflecting different depositional settings. Economic mineralization is hosted in the eastern assemblage rocks.

East of the Sr-706 line and now stratigraphically above the western assemblage rocks are autochthonous, continental shelf and slope carbonate and clastic facies of the eastern assemblage. These units include the Pennsylvanian-Permian Overlap Sequence, Mississippian Waterpipe Formation, Devonian Roberts Mountains Formation, Silurian-Ordovician Hanson Creek Formation, Ordovician Eureka Quartzite, and the Ordovician Pogonip Group. Carlin-type gold deposits in the Jerritt Canyon district are hosted in eastern assemblage units, in particular, the Devonian Roberts Mountains Formation and the Silurian-Ordovician Hanson Creek Formation and can be exposed in “erosional windows” in which the overlying western assemblage sediments are removed (Jones, 2005).

Allochthonous, pelagic, volcanic, and siliciclastic marine sediments including chert, shale, argillite, sandstone and greenstone are associated with the western assemblage. Formations within the assemblage include the Ordovician Snow Canyon Formation and the Devonian-Permian Schoonover Sequence. The western assemblage may have been deposited on the outer continental margin, adjacent to the rocks of the eastern assemblage (Turner *et al*., 1989). However, it may also have been part of an island arc accretionary prism system (Leslie, 1990).

The Ordovician Snow Canyon Formation is part of the Valmy Group. It is divided into three units, a lower, middle and upper. Sediments in the lower unit were likely deposited at the shelf/slope boundary in a tectonically active setting. Those in the middle unit were deposited by a sequence of turbidite flows, and those in the upper unit are interpreted to have formed in a similar setting to the lower unit sediments though in an area with less tectonic activity. Stratigraphically above the Snow Canyon Formation is the McAfee Quartzite, which is interpreted to also have formed at the shelf/slope boundary (Leslie, 1990).

The Jerritt Canyon District is located just east of the Sr-706 line, or near the stratigraphic transitional zone. The transitional assemblage of parautochthonous rocks reflects an intermediate zone with characteristics of both the western and eastern assemblages possibly as a result of oscillating conditions (Leslie, 1990).

Tectonic Setting

The Independence Range, as with much of Nevada, was affected by several deformation events (Figure 2). The earliest deformation event, the Ordovician to Silurian aged Ruby Disturbance, probably produced tight folding, uplift, and unconformities. The subsequent event, the Antler Orogeny, took place during the Late Devonian to Early Mississippian. The east-southeast directed Antler thrusting emplaced the Ordovician Snow Canyon Formation above the eastern assemblage carbonates. The Roberts Mountains thrust is the largest of the Antler thrust faults, transporting western assemblage rocks up to tens of kilometers (Hofstra, 1994; Wilton, 2005).

During the Permo-Triassic Sonoman Orogeny, a subsequent thrusting event, the Golconda thrust emplaced the Devonian-Permian Schoonover sequence above the Devonian Roberts Mountains Formation and the Permian Overlap Sequence. Other deformation events include the Pennsylvanian-Permian Humboldt Orogeny, the Late Jurassic Elko orogeny, and the Cretaceous-Tertiary Sevier orogeny. Eocene compression, with subsequent extension, resulted in further deformation and thrusting (Jones 2005; Wilton, 2005).

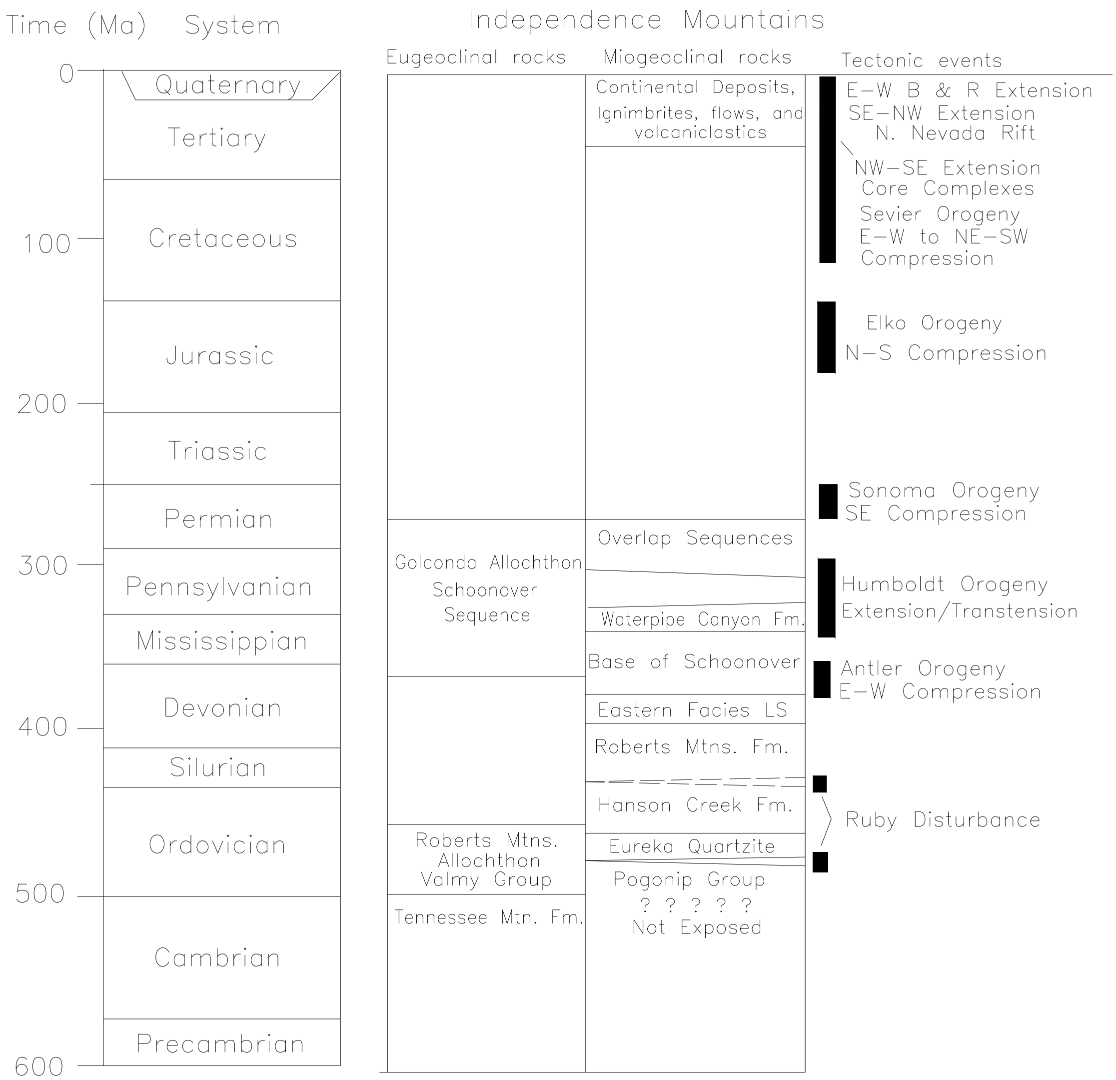

Figure 2. The Jerritt Canyon district was affected by numerous deformation events including the Ruby Disturbance, the Antler Orogeny, the Sonoman Orogeny, the Humboldt Orogeny, the Elko Orogeny, and the Sevier Orogeny (from Hofstra, 1994).

Structural Setting

Each deformation event imparted or reactivated a structural feature in the Jerritt Canyon district. For example, the Saval Discontinuity, located between Hanson Creek Formation and the overlying Roberts Mountains Formation, is associated with the Ruby Disturbance. Though there are different definitions of the Saval, including fault, breccia, unconformity, and discontinuity, in this paper it will be referred to as a discontinuity. The Ruby Disturbance is likely associated with other unconformities and disconformities in the district, such as within the Hanson Creek Formation and between the Eureka Quartzite and the Pogonip Group. During the subsequent Antler Orogeny, thrusting occurred along a west-northwest strike and resulted in a parallel, high-angle structural grain still present throughout the district. This east-southeast strike also follows the projection of the Wells fault (Thorman and Ketner, 1979). Tensional extension at the end of the Antler Orogeny was accommodated by northeast-striking faults. Northeast-striking features also parallel the Crescent Valley-Independence lineament (Peters, 1998).

The later Sonoman deformation event was oriented to the southeast, and more recent deformation reactivated structural features created during the Antler and Sonoman orogenies. For example, during Eocene age compression and extension, normal faults developed, and older faults were reactivated with a normal sense of displacement. In addition, the many deformation events, particularly those post-dating the Antler event, produced repetition of the eastern facies rock units, which is a very common feature in the district (Jones 2005; Wilton, 2005).

One of the most important and economical structural features in the district is the Saval Discontinuity, which represents the unconformity at the base of the Roberts Mountains Formation. The base of the Roberts Mountain Formation is commonly at a low angle to the bedding of older units and may be represented by a brecciated zone. This unconformity is believed to be early Paleozoic in age and can be a principal ore control (Jones, 2005). For example, at the Winters Creek gold deposit, ore is concentrated within the lower 40 m of the Roberts Mountains Formation, above the Saval Discontinuity (Bratland, 1991).

Folds are also a prominent feature in the district. In general, the folds trend WNW to ENE, verge to the south, range in scale from 5000 feet wide to 500 feet wide, and typically terminate on low angle thrusts. Fault propagation or fault-bend folding may be responsible for generating the folds. The timing of the folding is believed to be related to the late Paleozoic Humboldt orogeny, the Permo-Triassic Sonoman orogeny, or the Jurassic Nevada orogeny. However, a 320 Ma WNW-striking basalt dike cross cuts the folding (Phinisey *et al.*, 1996), suggesting the folding must be older, perhaps related to the Antler orogeny. The Antler orogeny though was east-directed which is unlikely to have produced east-west trending folds (Jones 2005; Wilton, 2005).

Stratigraphy

The rock units exposed in the Winters Creek area include the Eastern facies, autochthonous Hanson Creek Formation and the Roberts Mountains Formation; the Western facies, allochthonous Snow Canyon Formation and McAfee Quartzite; and the Tertiary Mill Site volcanic sequence. The Ordovician Hanson Creek Formation contains five units, labeled I through V. The units correspond to the stratigraphic order in which they appear, from top to bottom. In the Winters Creek open pit, only four of the five units were present, Hanson Creek I-IV. Nonetheless, exploration drill holes near the Winter Creek mine encountered Hanson V as well as the Ordovician Pogonip Group. Figure 3 shows the stratigraphic relationships of the autochthonous units, while figure 4 shows the stratigraphic relationships of the allochthonous units.

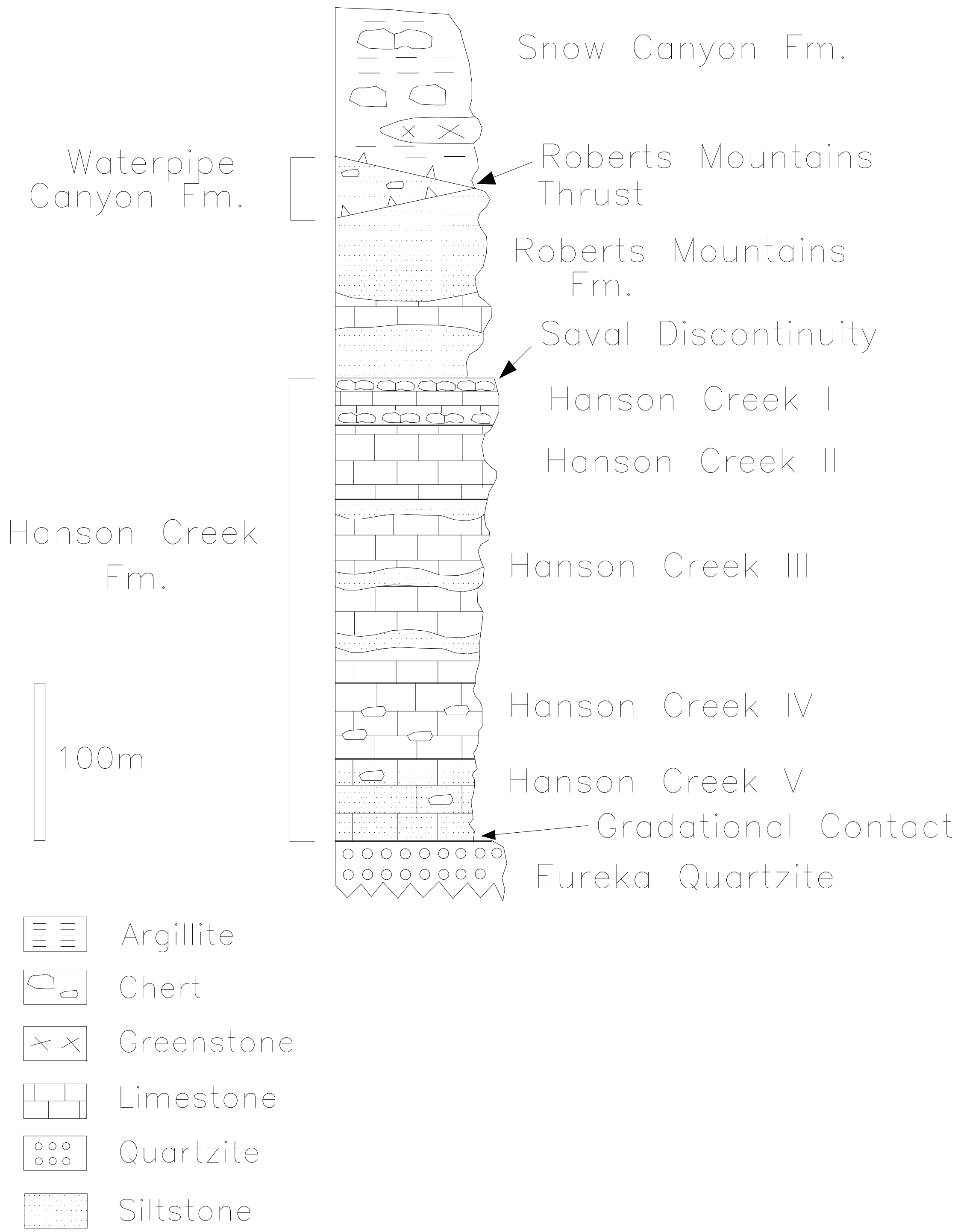

Figure 3. Generalized stratigraphic section for the Jerritt Canyon district (from Wilton, 2005).

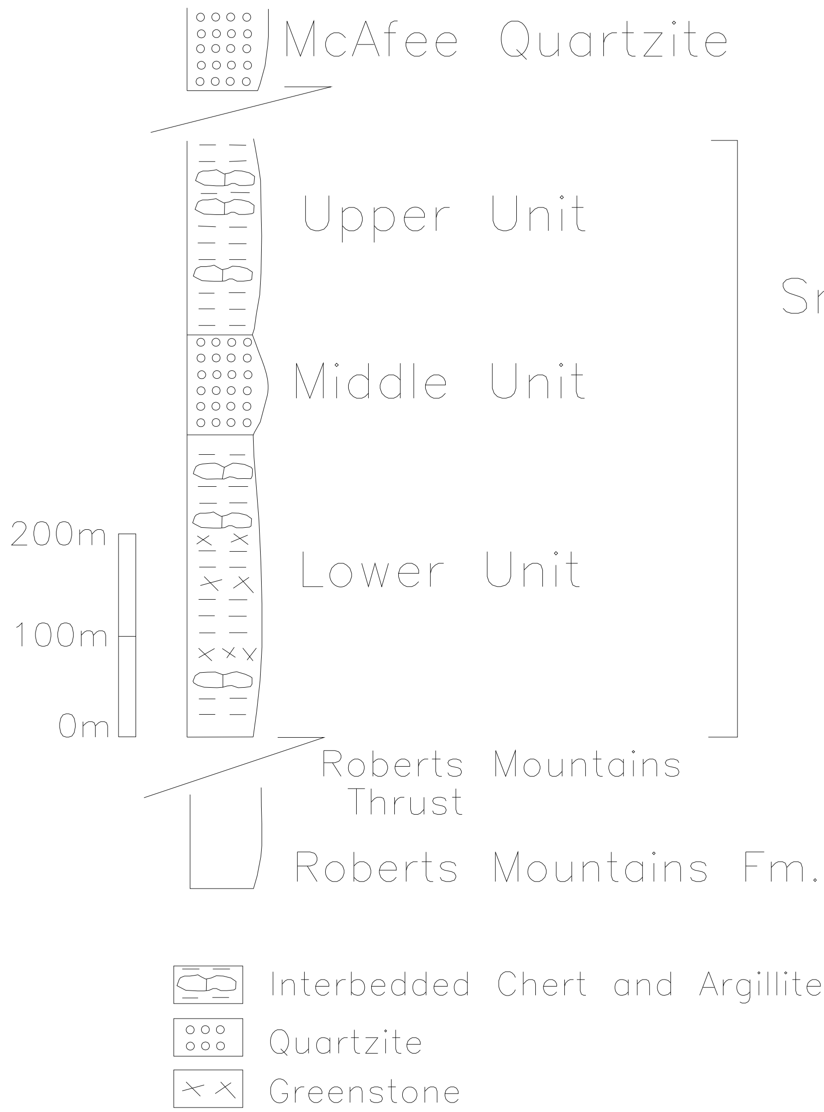

Figure 4. Generalized stratigraphic section of the allochthonous Snow Canyon Formation and McAfee Quartzite, members of the Valmy Group (from Leslie, 1990).

Autochthonous Units

The Ordovician Pogonip group, encountered solely in drill holes in the Winters Creek area, is composed of limestone, dolostone, and calcareous siltstones, as well as calcareous shale (Hofstra, 1994; Wilton, 2005). The unit is fossiliferous and typically unmineralized. In the central and western parts of the Jerritt Canyon district, the Pogonip is in gradational with the overlying Eureka Quartzite (Kerr, 1962).

Hanson Creek V, the oldest Hanson unit and the only unit not exposed in the Winters Creek mine, is a laminated, fine-grained limestone with chert nodules and calcareous siltstones. It can reac- 30 m in thickness (Wilton, 2005). Hanson Creek IV is a laminated, fine to medium-grained limestone with black chert nodules and chert beds. The unit is at least 82.3 m thick at Winters Creek, as defined by drilling. Hanson Creek III, conformably above IV, is an undulatory to planar bedded limestone with alternating layers of calcareous siltstone, averaging 2 cm thick, and carbonaceous micrite, averaging 5 cm thick. The maximum drilled thickness at Winters Creek mine is 80.7 m. Hanson Creek II is a thickly bedded, fine-grained limestone with local wispy laminated dolomitic zones. The average thickness is 18.2 m, as defined by drilling. The youngest unit, Hanson Creek I, lies conformably above II and is composed of alternating beds of black chert and tabular, fine to medium-grained, locally dolomitic limestone. On average, Hanson Creek I is 7.6 m thick at the Winters Creek deposit (Dewitt, 1999; Bratland, 1991).

Stratigraphically above the Hanson Creek Formation and above the Saval Discontinuity is the Silurian-Devonian Roberts Mountains Formation, which can range from 100 to 200 m thick. It has been divided into two units: a siltstone, the more common lithology and a limestone that is most commonly found near the base of the formation (Wilton, 2005). The Roberts Mountains siltstone is finely laminated, carbonaceous, and weakly to moderately calcareous (Fig. 5). The siltstone has interbeds of relatively resistant limestone. The Roberts Mountains limestone is also finely laminated and locally carbonaceous. The Roberts Mountains Thrust separates the top of the Roberts Mountains Formation and the base of the Snow Canyon Formation (Dewitt, 1999; Bratland, 1991).

Allochthonous Units

The lowest formation of the Valmy Group, the Ordovician Snow Canyon Formation, is the most prevalent unit exposed in the Winters Creek area. It is composed principally of chert (Fig. 6), though it contains sandstone, siltstone, greenstone (Fig. 7), argillaceous shale, mudstone, quartzite (Fig. 8), and sparse limestone. The Snow Canyon is approximately 600 m thick and is divided into lower, middle and upper units. The middle unit is the most resistant of the three and has the best natural exposure. The lower and upper are generally poorly exposed, particularly the upper unit as it can be covered by talus from the overlying McAfee Quartzite (Leslie, 1990).

Figure 5. Roberts Mountains siltstone.

Figure 6. Snow Canyon chert.

The lower unit, measuring approximately 300 m thick, is principally composed of argillite, or clay-shale, though also contains chert, greenstone, siltstone and rarely, quartzite and limestone. The chert and argillite display soft sediment deformation features, such as "cobblestone" textures. The chert is generally black due to carbonaceous staining, with white to colorless, cross-cutting, siliceous veins, though some siliceous veins contain carbon as well. Interbeds of siltstone are common in the lower unit. Typically, they are well-sorted, sub-angular and massive to laminated. Greenstones occur as lenses or pods within the chert or argillite. The greenstone pods are not continuous; instead, they may be fault bounded as locally there is breccia (Fig. 7) and deformation, twisting and convolutions, along the contact with argillite. Limestone is generally associated with greenstone and can be laminated or cross laminated. At the base of the unit are debris and grain flows (Leslie, 1990).

The middle unit, measuring approximately 100 m thick, is primarily composed of quartzite interbedded with argillite and siltstone. The quartzite (Fig. 8) is medium grained, moderately sorted, silica dominant (85-100 percent), and variably cemented by stained carbonate (0-15 percent). The orange-brown limonite stain is likely due to the weathering of sulfides, most likely pyrite. The interbeds of argillite are stained black to orange, due to carbon and limonite staining, respectively. The siltstone is also stained and is veined by polycrystalline quartz (Leslie, 1990).

Figure 7. Brecciated Snow Canyon greenstone in carbonate matrix.

Figure 8. Snow Canyon quartzite.

The upper unit of the Snow Canyon Formation is approximately 200 m thick and it is composed principally of chert interbedded with argillite siltstone and very minor quartzite. The chert has a pervasive, black, carbonaceous stain and contains abundant white, siliceous veins. Interbeds of black to tan colored argillite are commonly silicified, making the argillite resemble chert. Less abundant in the upper unit are interbeds of siltstone. The siltstone is typically brown to grey in color, well-sorted and grain-supported. The upper unit contains sparse greenstone, limestone and quartzite. The quartzite present in the upper unit is poorly sorted, fine to coarse-grained, stained, and primarily cemented by carbonate minerals (only 35 percent cemented by silica) (Leslie, 1990).

As previously stated, the depositional setting of the Snow Canyon Formation was proximal to the edge of the North American craton, and west of the Sr-706 line. Analysis of conodonts (Leslie, 1990) indicate the lower unit of the Snow Canyon Formation may have been deposited as early as the Late Cambrian; however, most of the conodonts collected were of Llanivirnian age, or Lower to Middle Ordovician age. The depositional setting for the lower, argillite dominant unit was the shelf/slope boundary. More specifically, the presence of argillite, chert and conodonts, suggests the depositional setting was deep marine, below the photic zone. Greenstone lenses and pods within the unit indicate a tectonically active setting. The presence of laminated siltstones further implies clastic input and proximity to a topographic high such as the shelf while the occurrence of basal debris and grain flows imply proximity to a slope (Leslie, 1990).

The middle Snow Canyon unit, dominantly composed of quartzite, is associated with cyclic turbidite flows and platform inundation. The sand comprising the turbidite deposits may have had the same source as both the Eureka and McAfee quartzites. (Leslie, 1990). Following the turbidite flows, the shelf/slope boundary returned to conditions associated with the lower unit, i.e. relatively deep marine and tectonically active. Under such conditions the upper unit was deposited. However, tectonically, the area was probably less active as the upper unit contains sparse greenstone pods (Leslie, 1990).

The Ordovician McAfee Quartzite is also part of the Valmy Group, and it was thrust above the Snow Canyon Formation, is (Fig. 9). The quartzite is light-colored, fine-grained, and massive with sparse interbeds of shale and siltstone. The McAfee Quartzite is the most resistant unit in the Valmy Group and, therefore, has abundant natural exposure. The McAfee Quartzite is interpreted to represent quartz flooding of the carbonate platform (Leslie, 1991). At the highest elevations, a coquina limestone (Fig. 10) is scattered on top of McAfee Quartzite subcrop and float. The limestone contains Neogene-age valvada mineetus and hydrobid (Firby, personal communication).

Figure 9. McAfee quartzite.

Figure 10. Fossiliferous coquina limestone with turritella in upper left corner. Neogene in age.

Mill Site Volcanic Sequence

In the Eocene, dacitic-andesitic Mill Site volcanic tuffs were emplaced. $^{40}Ar/^{39}Ar$ dates indicate an age of emplacement of 40.1-43.1 Ma (Hofstra,1994). The tuffs were later rotated 20-60 degrees to the east during Oligocene extensional block faulting (Zoerner, 2004).

The Mill Site volcanic sequence is located in the eastern part of the Winters Creek area in depositional contact and, locally, fault contact with the allochthonous Snow Canyon Formation and the McAfee Quartzite (Plt. 1). Brecciation and oxidation mark the fault contact (Fig. 11) as well as hydrothermal chalcedony flooding (Fig. 12). Overall, eutaxitic textures in the volcanic sequences dip to the east, suggesting that the tuffs filled an east-draining paleovalley (Henry, personal communication).

The Mill Site volcanic sequence is composed of ash-flow tuffs, lavas and volcanic sedimentary rocks. Stratigraphically, the oldest unit is a volcanic-sedimentary unit which rarely appears in outcrop as it is fairly nonresistant. The unit, labeled Tsilt on the map, is comprised of a pale gray, tuffaceous, lacustrine, fossil-bearing paper shale. Calcareous nodules, measuring several centimeters in diameter may also be present. Some of the fossils present in the unit have been identified as *Typha*, rush stems, angiosperms, insects (perhaps galmut insects), and metasequoia (Firby, personal communication). The metasequoia fossil (Fig. 13) dates the assemblage as Eocene in age.

Figure 11. Looking south at the fault contact between the buff tuff (left) and the Snow Canyon chert (right).

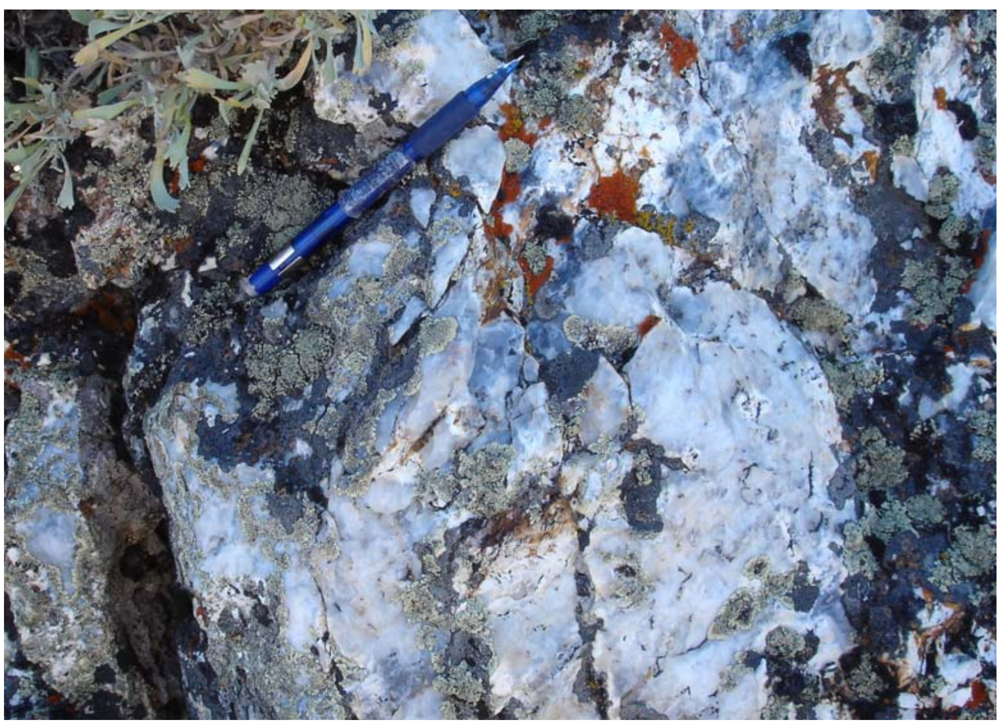

Figure 12. Chalcedony flooding on Snow Canyon chert along fault contact.

Figure 13. Eocene-aged metasequoia in the Mill Site tuffaceous shale.

Compositionally the Mill Site Volcanic Sequence contains two ash-flow tuffs, an older plagioclase-biotite tuff and a younger plagioclase-biotite-hornblende tuff. The plagioclase-biotite tuff can be further divided into two units, a pink tuff, labeled Tpt on the map (Plt. 1), and a buff-colored tuff, labeled Tbt. The pink tuff is located stratigraphically above the buff tuff, with a rubbly transitional zone between the two tuffs. In hand sample, the pink tuff appears more vitric and has a slightly finer matrix. However, both the pink and the buff tuffs are poorly-welded to unwelded, contain 5-20 percent visible crystal fragments, abundant pumice fragments, and abundant dark, scoriaceous lithic fragments.

The younger plagioclase-biotite-hornblende tuff ranges in color from red to pink to gray and to brown. The unit contains more visible crystal fragments, 20-35 percent, than the previously mentioned tuffs and is labeled Txp on the map (Plt. 1). In outcrop, the tuff contains few pumice fragments or fiamme and is more resistant and densely welded than the plagioclase-biotite tuff. Within the plagioclase-biotite-hornblende tuff is a dark gray to black vitric unit. The vitric unit contains approximately 40 percent visible crystal fragments of plagioclase, hornblende, pyroxene, and biotite, in order of abundance.

Locally, a conglomerate of well-rounded cobbles is associated with the volcanic sequences, though the relationship is not clear. The conglomerate is composed of cobbles of quartz, quartzite, chert, and siltstone. The conglomerate may represent Snow Canyon detritus (Zoerner, 2004). It may also be an intermediate unit between the Snow Canyon Formation and the volcanic sequences or it may be younger than the Tertiary volcanic sequence.

Structure

The prevailing structural grain in the Winters Creek area is east to northeast (Plts. 1 and 2). Some of the structural features trending in that direction include N70E-trending Deadman's Spring Anticline, sub-parallel high angle normal faults, the thrust contact between the McAfee Quartzite and the Snow Canyon Formation, the fault contact separating the volcanic sequences from allochthonous sequences as well as inferred faults within the volcanic sequences. There are also northeast-trending, parallel, high-angle normal faults that do not appear at the surface but are apparent in cross section; these are located in the erosional window of the Roberts Mountains Formation (Plt. 3 (cross section B-B')). Less common are high-angle, northeast-striking reverse faults. The high-angle faults are characterized by brecciation of upper and lower plate rocks, and dissolution and collapse breccias, particularly widespread in the lower plate units.

Furthermore, there are north to northwest-trending faults (Plts. 1 and 2). In the eastern part of Winters Creek there are northwest-striking faults in the Mill Site volcanic sequences, at the contact between the buff tuff and the Snow Canyon Formation, and at the contact between the Snow Canyon Formation and the McAfee Quartzite. The faults bounding the Snow Canyon are nearly parallel and dip to the southwest. The most northerly, at the contact with the McAfee Quartzite, is a reverse fault, while farther south at the contact with the Mill Site volcanics and within the Snow Canyon, normal faults are present. Farther south, the contact between the Snow Canyon Formation and the Roberts Mountains Formation strikes northwest and is possibly a northeast-dipping normal fault.

Thrust faulting is a widespread feature in the Winters Creek area. The contact between the lower plate assemblage and the upper plate assemblage is represented by a thrust fault (Plt. 2 (Roberts Mountains Thrust on cross section A-A')). The McAfee Quartzite was thrust on top of the Snow Canyon. Imbricate thrusting is pervasive within the eastern assemblage Roberts Mountains Formation and Hanson Creek Formation and may be present within the western assemblage Snow Canyon Formation and McAfee Quartzite. Thrust faults are characterized by strongly developed breccias, and dissolution and collapse of eastern assemblage rocks. In relation to the younger high angle faults, the thrust faults can be offset, dragged, or terminate on the high angle faults.

Jerritt Canyon District Mineralization

The district contains several sedimentary-hosted, Carlin-type gold deposits hosted in an autochthonous assemblage of Paleozoic shelf facies silty carbonates, in particular, the Devonian Roberts Mountains Formation and the Silurian-Ordovician Hanson Creek Formation. These silty carbonates are permeable and, consequently, were receptive to mineralizing fluids. Economic mineralization, therefore, can be stratigraphically controlled. For example, at the Marlboro Canyon deposit, ore is found in the Hanson Creek Formation, particularly in units II and III. Additionally, ore can be restricted to a single imbricate sequence, such as at the DASH deposit.

Moreover, hydrothermal fluids were localized by high-angle structures that generated secondary permeability. Mineralized rocks can be associated with structures oriented west-northwest and northeast, and particularly at the intersection of two such features. Where two structural features intersect, ore zones preferentially trail the west-northwest striking feature with typical ore zones ranging in length from 500 feet to 5000 feet long, and widths ranging from 200 feet to 600 feet. High-angle structural features, as well as thrust faults, bedding plane faults, and the Saval Discontinuity, induced secondary permeability, making the silty carbonates ever more receptive to mineralization. For example, at the Murray mine, ore is located at the Saval Discontinuity between the Roberts Mountains Formation and the Hanson Creek Formation (Jones, 2005).

Mineralization, as gold-bearing arsenian pyrite and/or marcasite, is associated with calcareous rocks, dolomite, jasperoid and/or dikes. Alteration around ore zones is wide ranging including silicification, decarbonatization, sulfidation, carbon enhancement, argillization, and oxidation. Carbonaceous refractory ore yields more gold than jasperoid ore. As with many Carlin deposits, the minerals most commonly associated with economic mineralization are pyrite and realgar (Hofstra, 1995 and Jones, 2005).

Many deposits in the district have associated dikes. In particular, dikes cross cutting the Paleozoic shelf facies are commonly mineralized. Of the 18 mined deposits in Jerritt Canyon, only four, including Winters Creek, do not appear to contain mineralized dikes. Argillic alteration is associated with the mineralized dikes (Jones, 2005).

Winters Creek Gold Mine

At the Winters Creek gold deposit, ore is hosted in the Roberts Mountains Formation that is visible through an erosional window in the upper plate rocks. Though the Roberts Mountain Formation hosts most of the mineralization, a portion is also hosted in the Hanson Creek Formation. The Deadman's Spring anticline, trending N70E, was the principal control on mineralization. The anticline is asymmetric—the southern limb is steeper, dipping 30 to 50 degrees, than the northern limb which dips 20 to 30 degrees. Oriented sub-parallel to the anticline fold axis are high angle reverse faults which cut the doubly plunging anticline. South-directed compression during the Sonoman Orogeny may have generated the Deadman's Spring anticline and the associated sub-parallel faults. These N70E trending features are then offset by high angle, northwest trending faults which may have been generated during extensional tectonism from 35-10 Ma.

The economic mineral deposit was concentrated within the lower 40 m of the Roberts Mountains Formation, above the Saval Discontinuity. However, some mineralization also occurred within the Discontinuity and below in the Hanson Creek Formation. The Saval Discontinuity is characterized by silicificied, decarbonatized, carbonized, and brecciated rock (Bratland, 1991).

The most abundant alteration products in the Winters Creek gold deposit are silicified rocks though oxidized, argillized, and carbonized rocks are also prevalent. Silicification of the autochthonous Hanson Creek Formation and Roberts Mountains

Formation produced jasperoids. In general, ore-grade gold is not located in the jasperoids though it is associated with intensely silicified rocks and jasperoids. Post-jasperoid silicification produced crosscutting quartz veins, quartz overgrowths, and drusy quartz (Bratland, 1991).

Zones of remobilized carbon are associated with ore zones. Carbon remobilization was common in the carbonate units of the Hanson Creek Formation and Roberts Mountains Formation, and was localized by both high and low angle structural features. Carbonatized zones were commonly argillized as well. As with silicification and carbonization, argillization and oxidation affected both lower plate carbonate units, but the effects were more minor in the Hanson Creek Formation (Bratland, 1991).

Geology North of the Mine

As previously discussed, an erosional window exposed the Roberts Mountains Formation at the Winters Creek gold deposit. This host was intercepted in the most northern part of the erosional window by one reverse circulation drill hole with 40 ft averaging 0.057 opt and containing a 5 ft interval of 0.1899 opt Au. The surficial, northern extent of the Roberts Mountains unit is in contact, likely thrust contact, with the overlying Snow Canyon Formation (Plate 1). North of the Winters Creek open pit, the allochthonous Ordovician Snow Canyon Formation is the most prevalent unit in surface exposures, though alluvial cover is also abundant. The northernmost part of the map area, which also has the highest elevations, contains the McAfee Quartzite, while the easternmost part of the map area contains a mid-Tertiary volcanic sequence composed of ash-flow tuffs and volcanic sedimentary rocks in depositional contact and, locally, fault contact with the upper plate rocks.

Petrography

Hanson Creek Formation

In the Winters Creek area, Hanson Creek I, II and III are present in outcrop and are typically brecciated and intensely silicified, forming jasperoids. In hand sample and in thin section, Hanson Creek I is a fragment-supported breccia with a siliceous matrix. The fragments consist of carbonate minerals replaced by silica. The vugs are filled principally with comb quartz overgrown by a paragenetically later chalcedonic quartz rim. Within the matrix are inclusions of iron-bearing carbonate minerals, possibly ankerite. The inclusions have a relatively iron-rich rim and iron-poor center (Fig. 14). Also in the quartz matrix is a single inclusion of iron-stained illite and possibly sericite (Fig. 15).

Samples of Hanson Creek II and III also include intensely silicified, brecciated carbonates, or jasperoids (Fig. 16). Both comb (Fig. 17) and mosaic-like quartz veins are present. Hanson II can be distinguished as it contains trace amounts of carbonate minerals and is weakly stained by limonites while Hanson Creek III contains fewer quartz veins and trace amounts of opaque minerals.

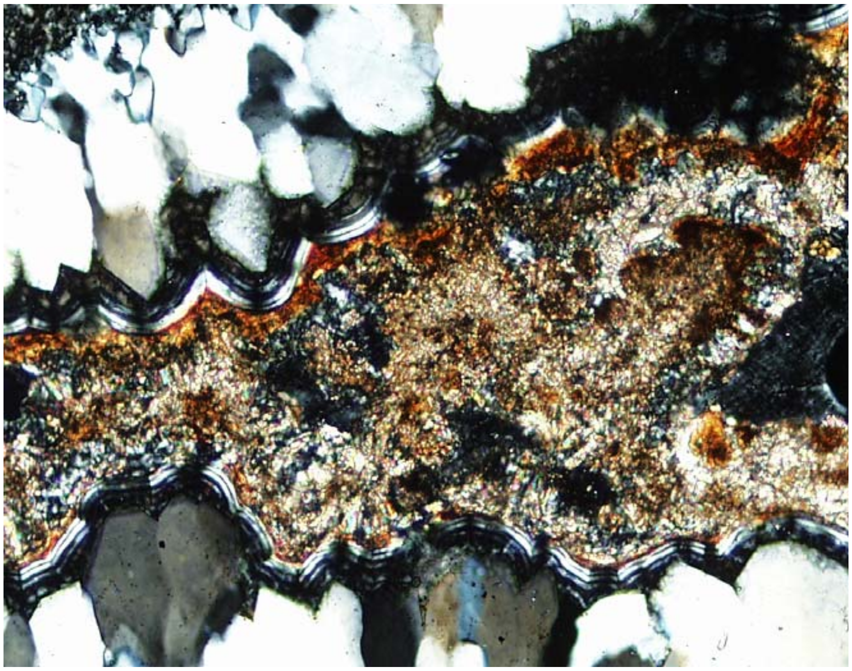

Figure 14. Hanson Creek I. Quartz with a chalcedonic rim and an inclusion of iron-bearing carbonates, possibly ankerite. The inclusion has a relatively iron-rich rim and iron-poor center. X-pol. FOV = 0.85mm.

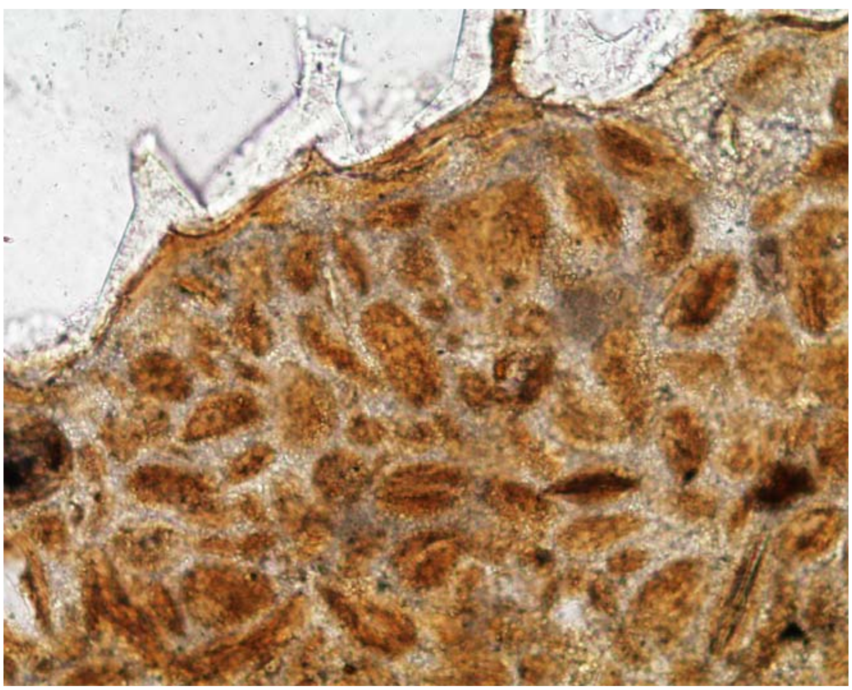

Figure 15. Hanson Creek 1. Inclusion of iron-stained illite (and possibly sericite). Plane light. FOV = 0.43mm.

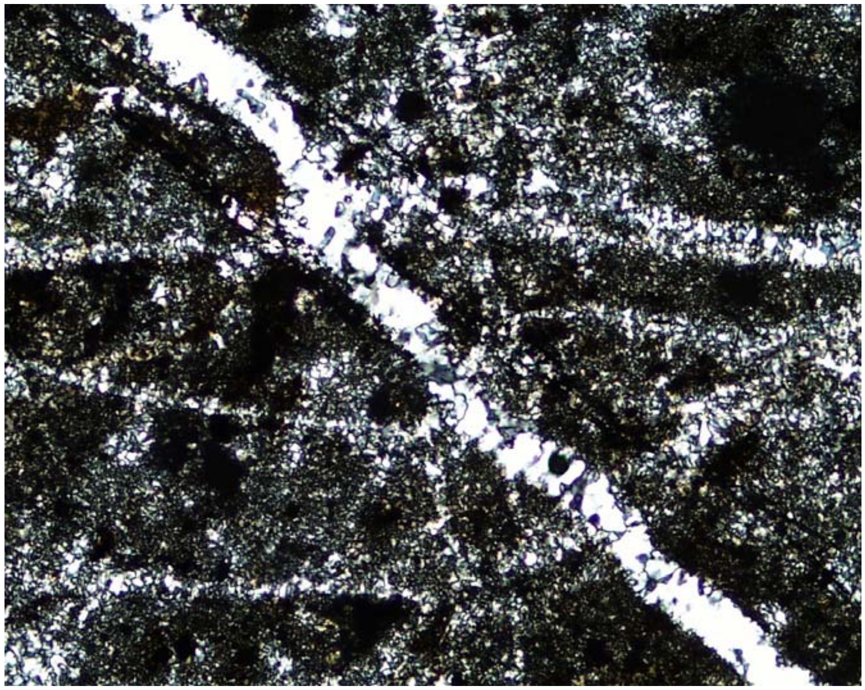

Figure 16. Hanson Creek II. Silicified carbonate, jasperoid. X-pol. FOV = 0.85mm.

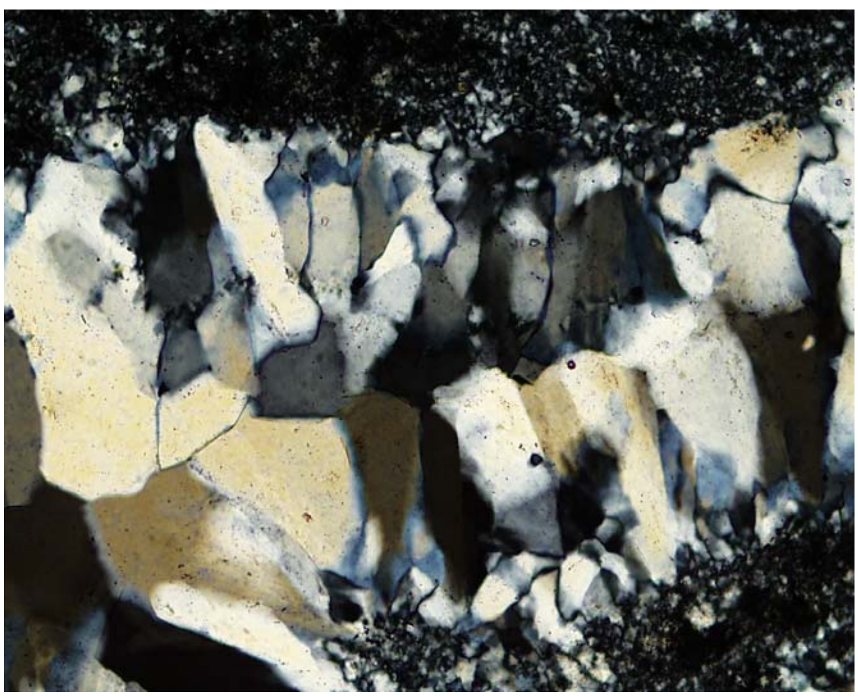

Figure 17. Hanson Creek II. Vein of euhedral comb quartz. X-pol. FOV = 0.85mm.

Roberts Mountains Formation

The Roberts Mountains limestone is composed of approximately 60 percent very-fine grained carbonate grainss, 10 percent coarse carbonate grains, 10 percent quartz grains, and 20 percent opaque minerals and carbonaceous material (Fig. 18). On average, the carbonate minerals measure less than 0.01 mm in length. While the limestone is very weakly laminated, the Roberts Mountains siltstone is finely laminated with laminations measuring sub-millimeter in scale and defined by relatively carbon-rich and carbon-poor layers. The siltstone is composed of approximately 45 percent quartz grains, 35 percent fine-grained carbonate grains, and 20 percent opaque minerals and carbonaceous material.

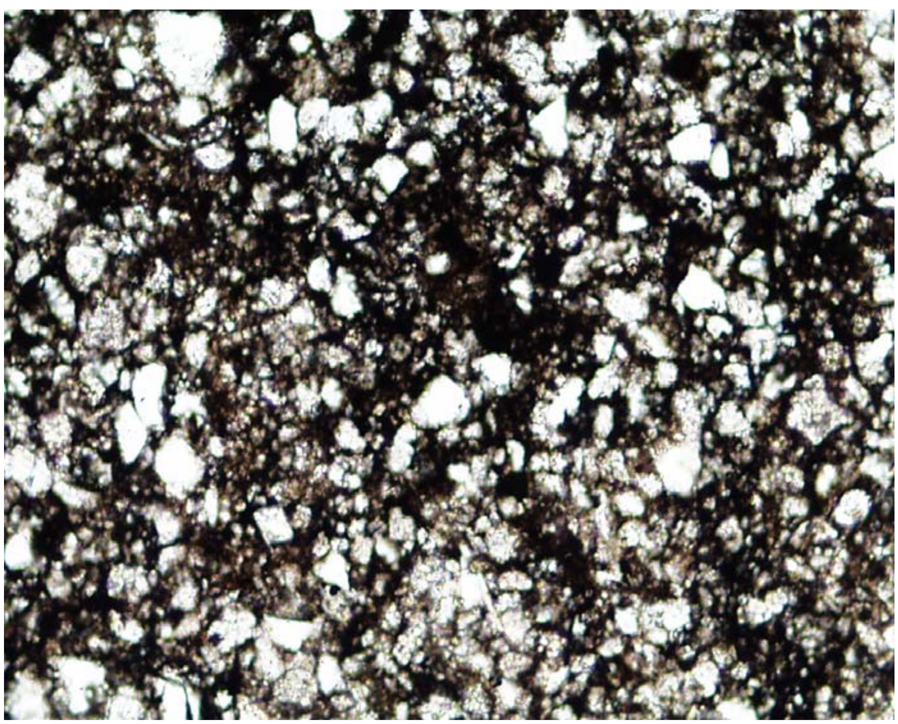

Figure 18. Roberts Mountain limestone, composed of carbonates, quartz, opaque minerals and carbonaceous material. Plane light. FOV = 0.85 mm.

Snow Canyon Formation

In the Winters Creek area, the Snow Canyon Formation contains rocks of various lithologies including chert, argillite, sandstone, limestone, and greenstone. The chert is composed of very fine-grained quartz, measuring less than 0.01 mm in length, iron oxide minerals, and carbonaceous material, which imparts a black to brown color to the rock. The chert is moderately to intensely veined by quartz and carbonate minerals (Fig. 19). Carbonate minerals are present as very fine-grained masses around quartz veins, as coarsely crystalline grains within quartz veins, and as cross-cutting veins. The carbonate minerals may be weakly altered to sericite and chlorite. Multiple generations of quartz veins contain both euhedral quartz and chalcedonic quartz. In general, chalcedonic quartz veins and carbonate veins cross cut the euhedral quartz veins. Many of the thicker chalcedonic veins have coarsely crystalline interiors and finely crystalline vein selvages. In addition, fine-grained chalcedonic quartz veins cross cut the coarser-grained, wider chalcedonic veins.

Though the Snow Canyon sandstone is pervasively stained by iron oxides, it is composed primarily of quartz grains measuring less than 0.5 mm. Some of the larger quartz grains, particularly the more euhedral crystals, have zones rich in apatite inclusions (Fig. 20). Conversely, the Snow Canyon limestone is composed of approximately 99 percent carbonate minerals, both very fine-grained and coarse-grained varieties, and is cut by coarsely crystalline carbonate veins. Opaque minerals and quartz account for the remaining 1 percent of the rock. The limestone can be variably carbonaceous, imparting a black stain on the carbonate minerals.

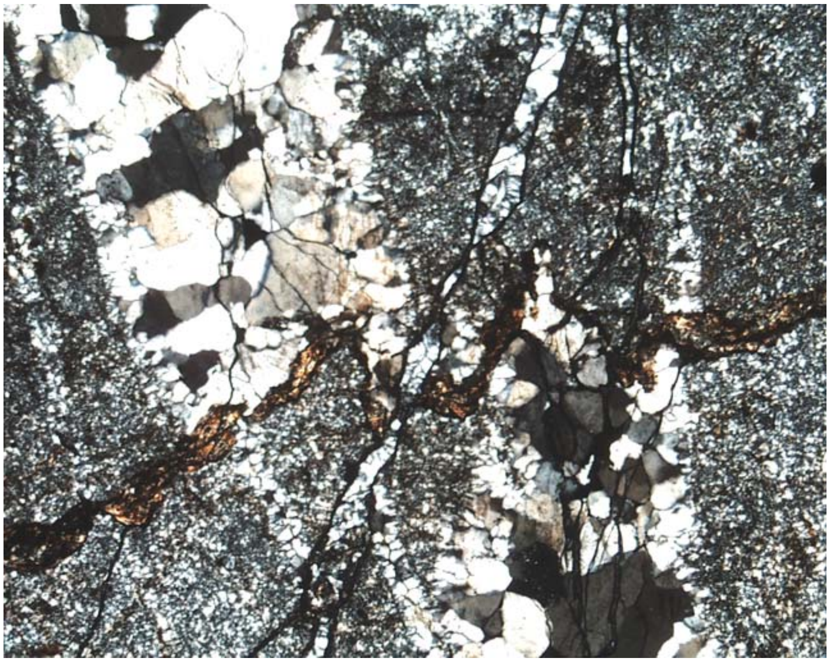

Figure 19. Snow Canyon chert with multiple generations of veins. Chalcedony rimmed quartz vein is offset by a thin carbonate vein (brown) which is offset by a thin chalcedony vein. X-pol. FOV = 0.85mm.

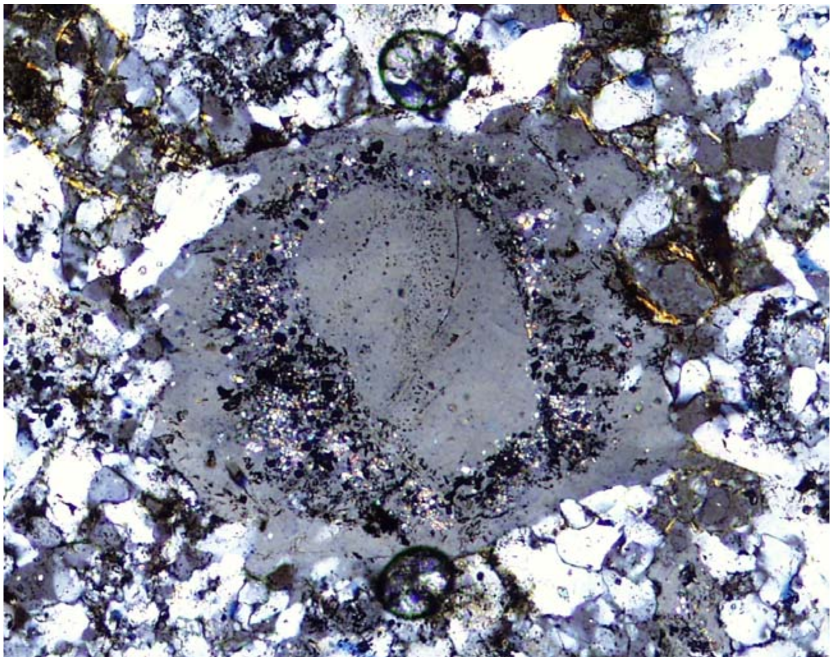

Figure 20. Snow Canyon sandstone. In the center is a quartz grain with a zone rich in apatite inclusions. X-pol. FOV = 0.85mm.

The Snow Canyon greenstones range from porphyritic to aphyric to amygdaloidal. Such a range in textures may suggest a range in cooling rates. In addition, feldspar crystals can be aligned, exhibiting a pilotaxitic texture. The primary minerals comprising the greenstones are carbonates, quartz, alkali feldspars, chlorite, clays, magnetite, hematite ± amphiboles, and pyroxenes. Though only one brecciated greenstone sample contains variolites (Fig. 21); vesicle infilling by calcite, chlorite, sericite ± zeolites is common, and the majority of vesicles also having a chalcedonic quartz rim (Figs. 22 and 23). Both siliceous veins as well as carbonate veins are common in the greenstone.

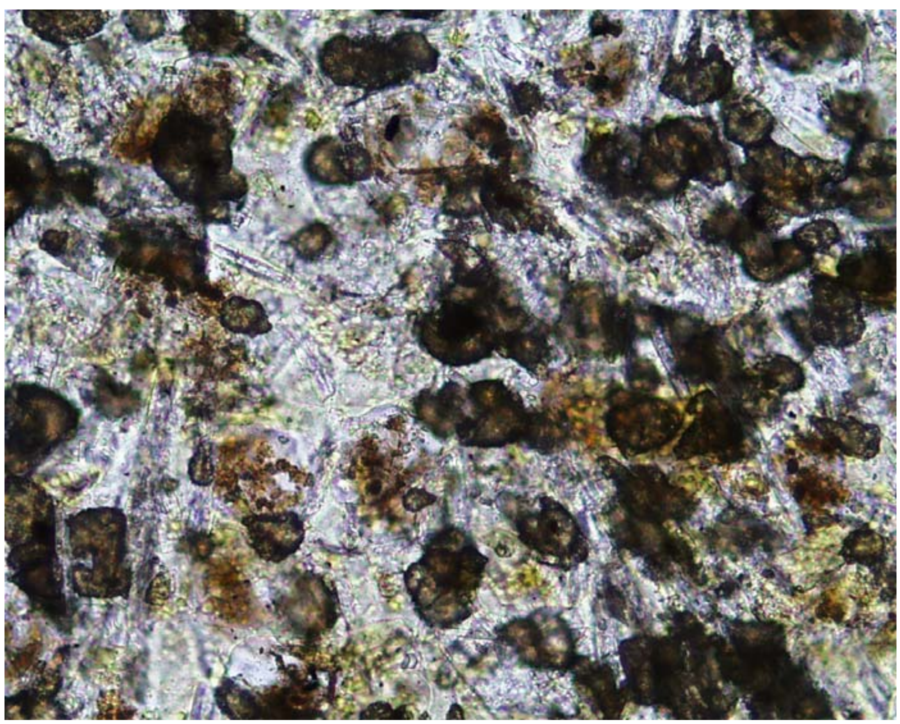

Figure 21. Snow Canyon greenstone with abundant variolites (brown). X-pol. FOV = 0.43 mm.

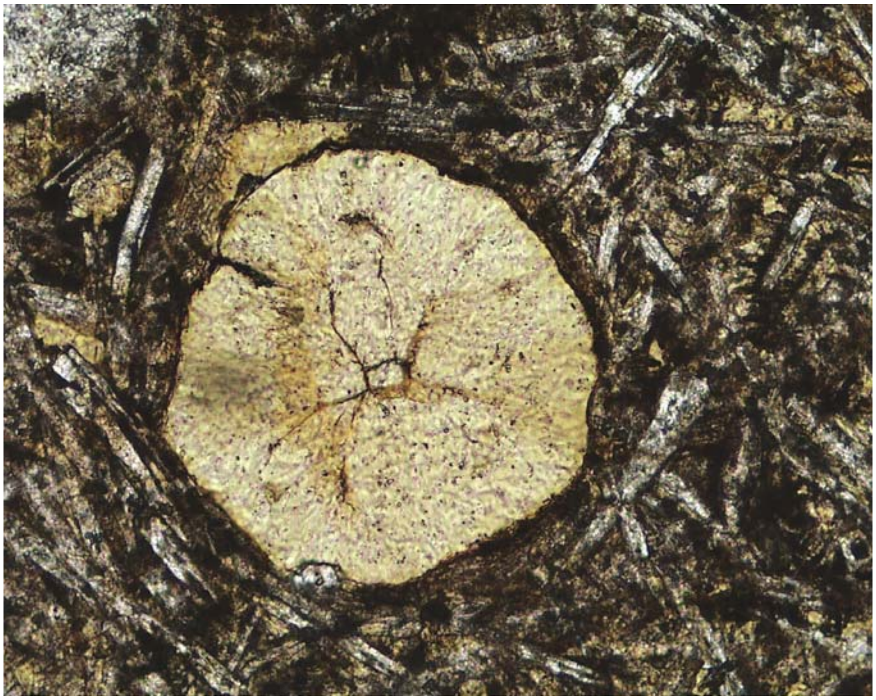

Figure 22. Snow Canyon greenstone with calcite-filled amygdule within plagioclase microlites. Plane light. FOV = 0.85 mm.

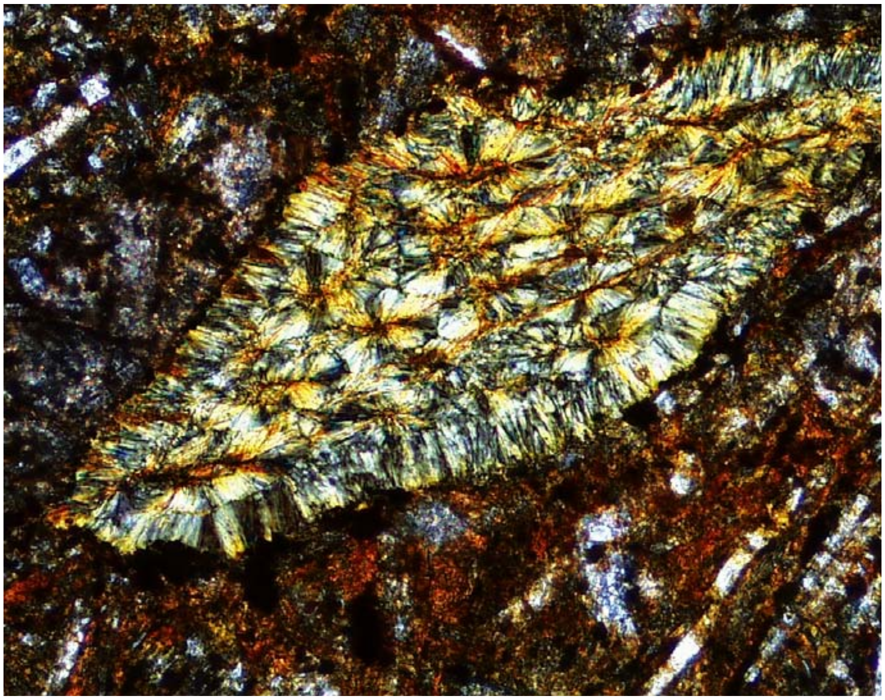

Figure 23. Snow Canyon Greenstone. In the center is a stretched vesicle filled with chlorite and zeolites ± sericite. X-pol. FOV = 0.85 mm.

All of the greenstone samples are strongly altered such that identification of primary minerals is difficult. Carbonate alteration, produced ankerite, calcite, dolomite, quartz, albite, sericite, chlorite, and rutile. Though feldspars are now pervasively altered to calcite and phyllosilicates such as sericite, the parent feldspars may have been calcic plagioclase crystals that were albitized and later affected by carbonate alteration, suggesting sea-floor metasomatization and spilitization preceded the carbonate alteration phase. The abundant calcite found throughout the greenstones, in addition to within the relict feldspars, suggests the unaltered greenstone was relatively calcic and spilitic before metasomatic alteration and carbonate alteration (Leslie, 1990).

Ash-flow Tuffs

The buff tuff is a glassy, poorly welded ash-flow tuff comprised of approximately 35 percent non-matrix material. Though much of the groundmass is glassy, locally there are zones of granophyric recrystallized quartz and sericite. The majority of the fragments, roughly 40 percent, are glass shards with no evidence of compaction. Plagioclase phenocrysts, as large as 1 mm in length, comprise about 30 percent of the total fragments. They exhibit compositional growth zoning and contain sparse inclusions of apatite (Fig. 24). Quartz, as large as 1 mm in length, and biotite altered to sericite each comprise 10 percent of the non-matrix material. Lithic fragments and other xenoliths together comprise the remaining 10 percent of non-matrix material. Lithic fragments are composed of quartz sandstone (Fig. 25), the average grain measuring approximately 0.08 mm in length, and trace amounts of carbonate minerals. Some xenoliths are characterized by trachytic plagioclase laths and microlites, and have an igneous origin.

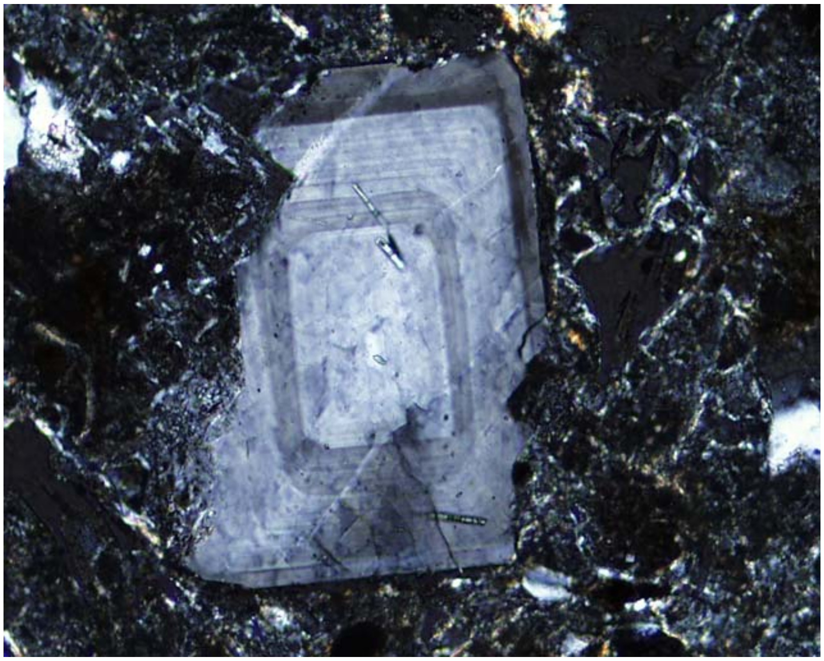

Figure 24. Plagioclase-biotite buff tuff with compositionally zoned plagioclase fragment and included apatite euhedrals. The groundmass contains some granophyric recrystallized quartz and sericite. X-pol. FOV = 0.85mm.

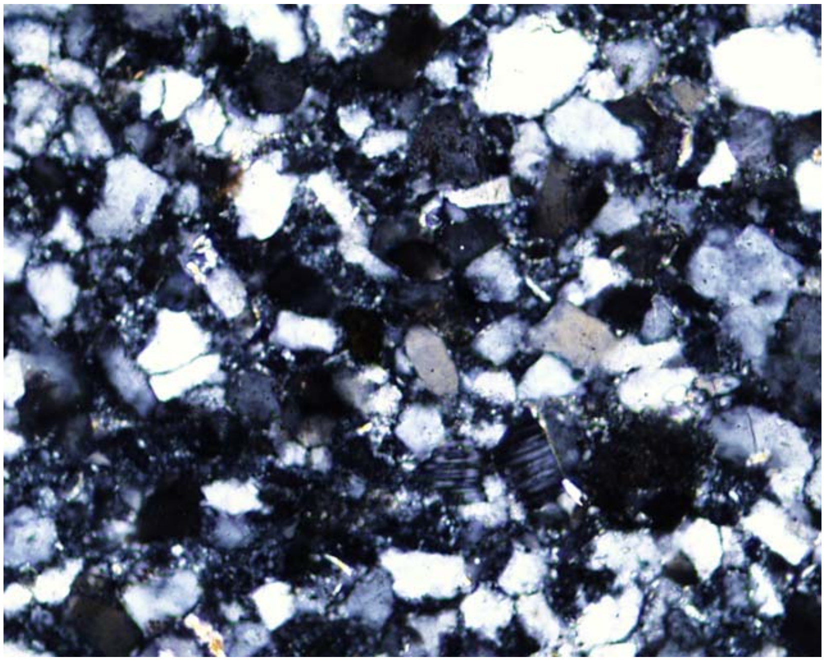

Figure 25. Sandstone lithic fragment present in the plagioclase-biotite buff tuff. X-pol. FOV= 0.85 mm.

The pink tuff is a devitrified, poorly to moderately welded ash-flow tuff with approximately 30 percent non-matrix material. The groundmass is composed of granophyric quartz and sericite. Plagioclase is the most abundant phenocryst, comprising 60 percent of the non-matrix material. As with the buff tuff, plagioclase phenocrysts in the pink tuff can measure as large as 1 mm in length and may contain inclusions of apatite and rutile. Biotite comprises 20 percent of the non-matrix material, measures at most 0.4 mm in length, and is partially altered to sericite and hematite. Opaque minerals, less than 0.2 mm in length, comprise approximately 10 percent of the non-matrix material. Glass shards, less than 0.4 mm in length, and xenoliths, as large as 1 cm in length, each comprise 5 percent of the non-matrix material. Glass shards, partially altered to quartz and sericite, exhibit weak to no compactional foliation (Fig. 26), and some exhibit axiolitic and spherulitic devitrification textures. The xenoliths, as in the buff tuff, are characterized by trachytic plagioclase laths and microlites (Fig. 27).

The plagioclase-biotite-hornblende tuff (Fig. 28 and 29) and lava is devitrified, poorly to strongly welded, and contains between 25-35 percent non-matrix material. Plagioclase is the most abundant phenocryst, making up 50-70 percent of the non-matrix material. It can measure 3 mm long and contain inclusions of apatite and rutile. Carlsbad twins, albite twins and compositional growth zones are common. In some phenocrysts, the calcium-rich core has weathered out. Biotite comprises between 5-10 percent of the non-matrix material. In general, biotite is 0.5 mm in length or less and is partially altered to iron oxides. Mafic mineral content ranges from trace amounts to 10 percent of the non-matrix material. Distinguishing between hornblende and pyroxene is difficult

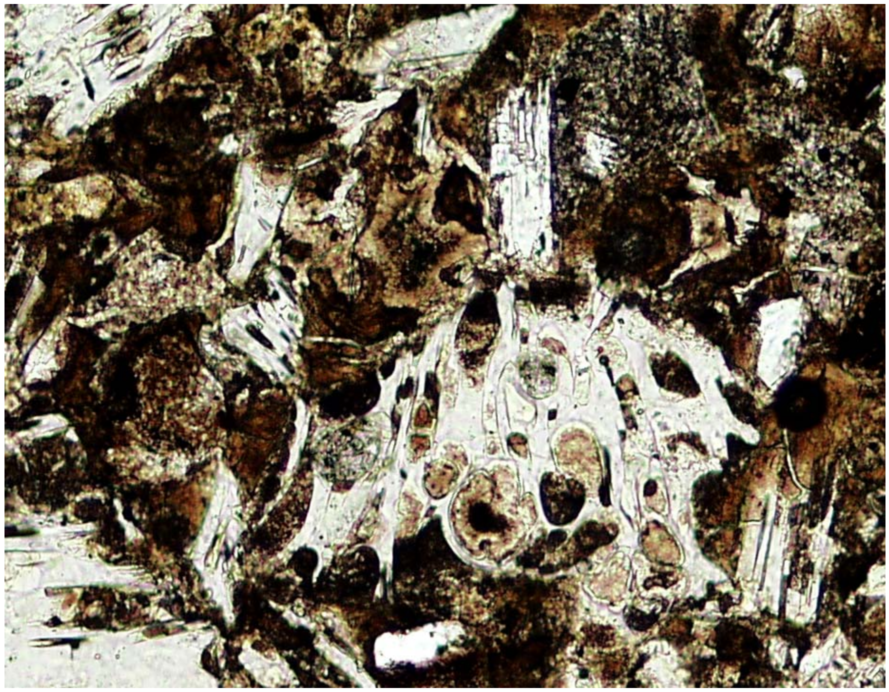

Figure 26. Plagioclase-biotite pink tuff. No compaction of glass, as evident by the frothy texture (center, right). Plane light. FOV = 0.85 mm.

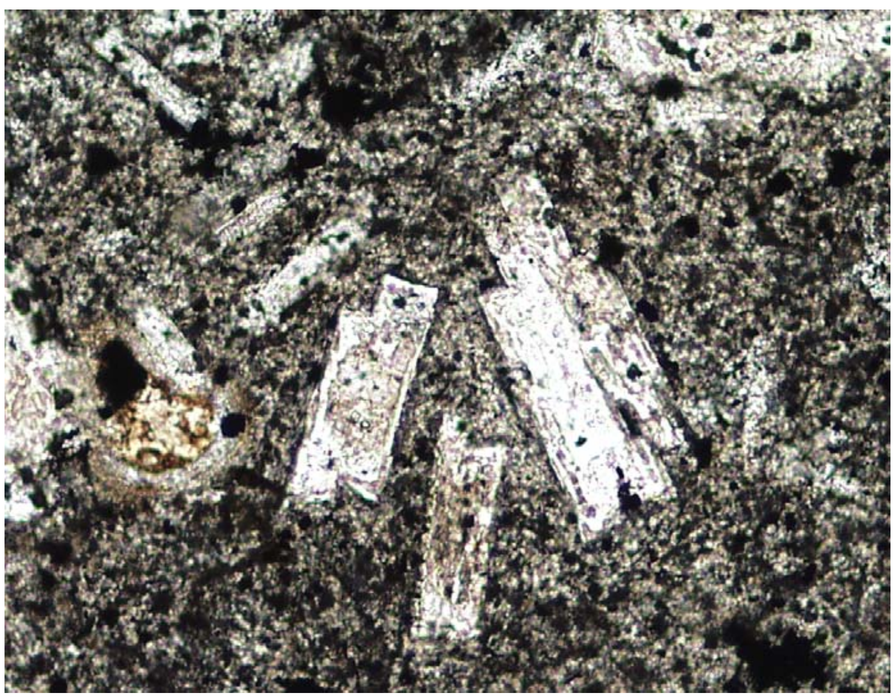

Figure 27. Xenolith with trachytic plagioclase laths and microlites, present in the plagioclase-biotite pink tuff. Also present in the buff tuff. FOV = 0.85 mm.

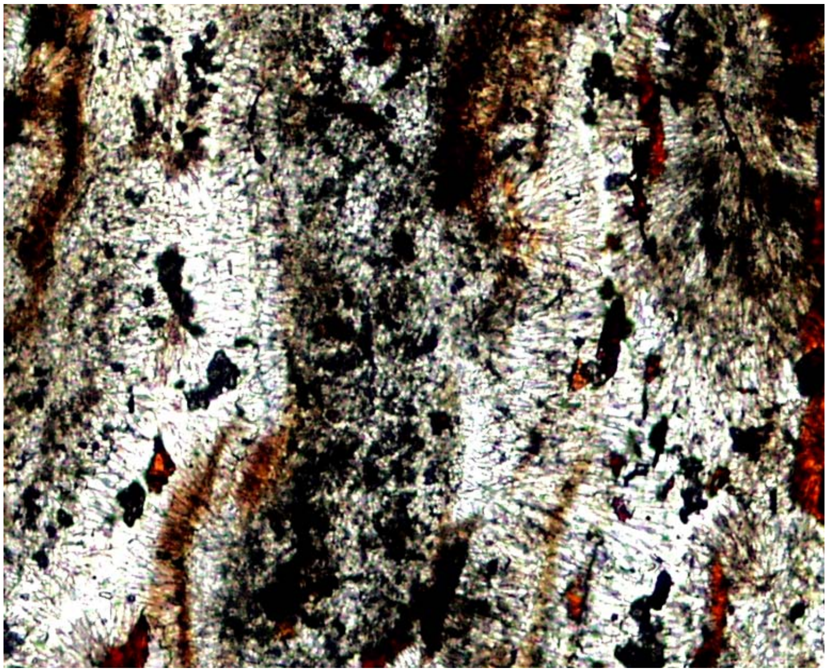

Figure 28. Plagioclase-biotite-hornblende tuff. Glass shards have been compacted and devitrified and exhibit axiolitic textures. Plane light. FOV = 0.85mm.

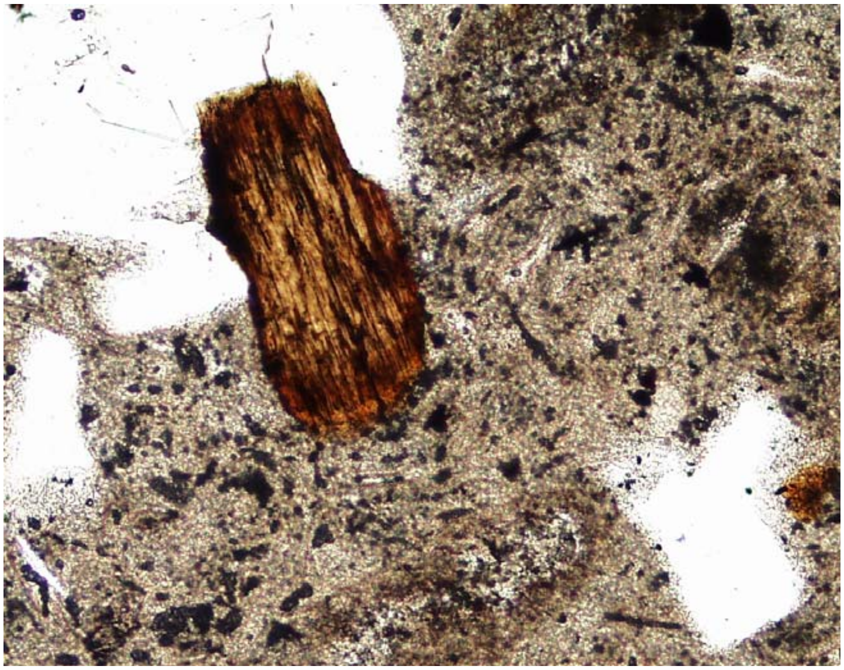

Figure 29. Plagioclase-biotite-hornblende tuff. Plagioclase (white) and biotite (brown) in a devitrified matrix. Plane light. FOV = 0.85 mm.

as the grains are altered to sericite and chlorite; however, the relict cleavage suggests hornblende. Glass shards can comprise up to 10 percent of the total non-matrix material. Glass shards can measure up to 3 mm in length and are variably altered to quartz and sericite. Opaque mineral content ranges from 5-20 percent of the total non-matrix material with minerals measuring at most 0.5 mm in length. Quartz is present in trace quantities and is up to 0.5 mm in length. The unit also contains sparse lithic fragments of quartz sandstone, and xenoliths with trachytic plagioclase laths and microlites.

In thin section, the black plagioclase-biotite-hornblende unit (Fig. 30) contains between 40 and 45 percent non-matrix material. The groundmass is strongly welded and exhibits rheomorphic flow features. Though the groundmass is generally glassy, it also contains recrystallized, granophyric sericite and quartz and scarce perlitic fractures. Plagioclase is the principal phenocryst, comprising 35-50 percent of the non-matrix material. Phenocrysts measure as large as 2.5 mm in length, are weakly oxidized, and may have inclusions of apatite and rutile. Albite twins, Carlsbad twins and growth zones are common. Hornblende, measuring up to 0.8 mm in length, accounts for 15-20 percent of the non-matrix material. Pyroxene phenocrysts, typically smaller than the hornblende, account for 10-25 percent of the total non-matrix material. Biotite which can measure 2 mm in length comprises 10-20 percent of the non-matrix material and opaque minerals typically comprise 5 percent of the non-matrix material. Lithic fragments are typically present and can be aphanitic, felty or porphyritic. Porphyritic lithic fragments contain euhedral phenocrysts of plagioclase and amphiboles (Fig. 31).

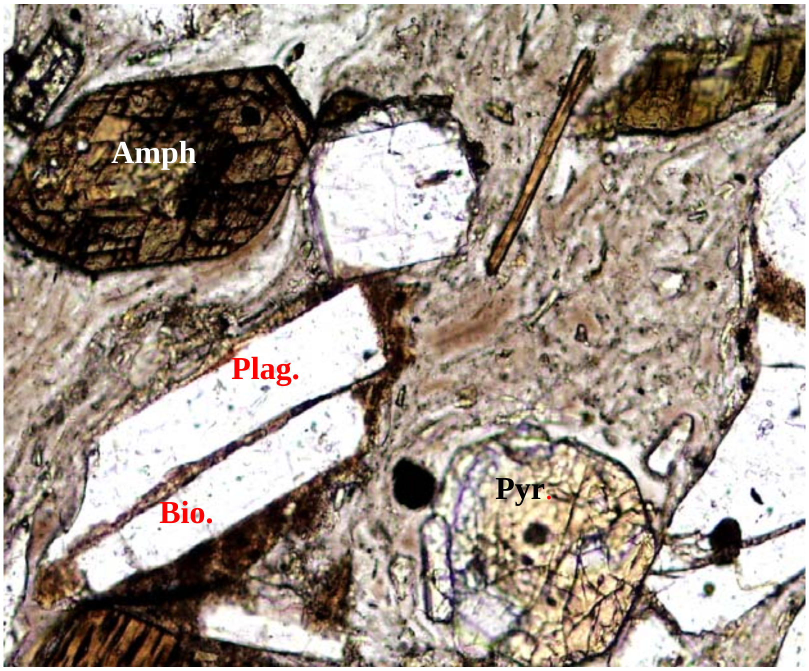

Figure 30. Plagioclase-biotite-hornblende vitric tuff with phenocrysts in a glassy matrix. Plane light. FOV = 0.85 mm.

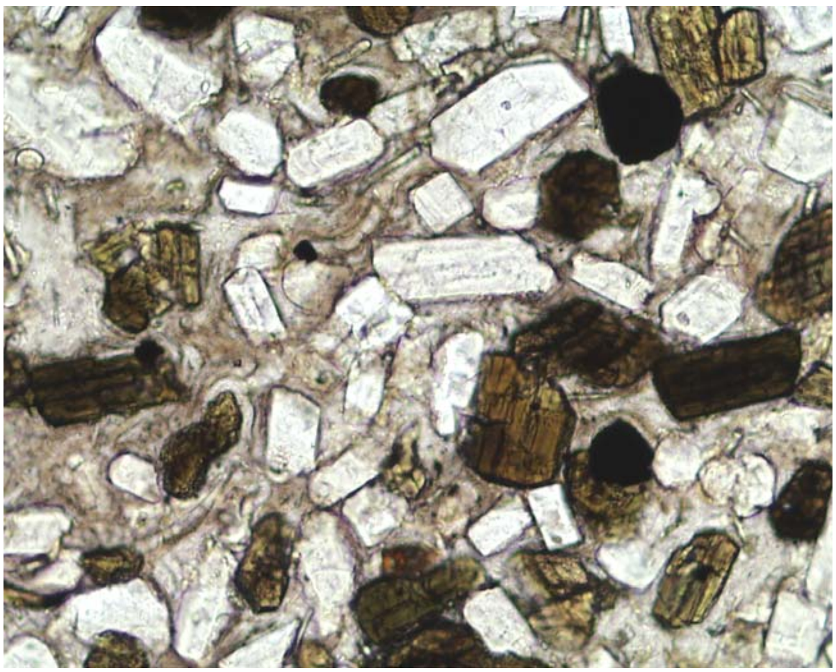

Figure 31. Lithic fragment with phenocrysts of plagioclase and amphibole, present in the plagioclase-biotite-hornblende vitric tuff. Plane light. FOV = 0.85 mm.

Soil Geochemistry

Data from a soil sample grid were provided by Queenstake Resources Inc. for the Winters Creek area. The samples were collected by Queenstake Resources Inc. over many years and compiled. Gold values range from <1 ppb to 1230 ppb, with over 95 percent of the samples containing less than 15 ppb Au. The remaining 5 percent are for the most part located off the haul road or in drainages extending from the haul road. For statistical purposes, those samples contaminated by drainage from the haul road have been removed from the sample set and labeled contaminated (Fig. 32). Once, removed, the mean gold value for the Winters Creek area is 3.68 ppb and the standard deviation is 10.37 ppb. A histogram of the Au values suggests there is only one population present in Winters Creek (Fig. 33).

A plot of the gold values color coded such that grey represents values within the mean plus one standard deviation, green represents samples within two standard deviations, orange within three and red yet higher reveals and categorizes the anomalous soil gold values, or those greater than the mean plus one standard deviation (Fig. 32). For example, there are anomalous values, west of the Winters Creek open pit, and near the edge of the Roberts Mountains erosional window. There are also soil samples with anomalous Au values north of the Winters Creek open pit and near the thrust contact between the Snow Canyon Formation and the McAfee Quartzite which corresponds with the location of greenstone float and possibly the lower section of the Snow Canyon Formation. Though soil anomalies commonly follow structural trends in the Jerritt

Canyon district, in the Winters Creek area there are also anomalous gold values within the Snow Canyon Formation that do not appear to be associated with any structures.

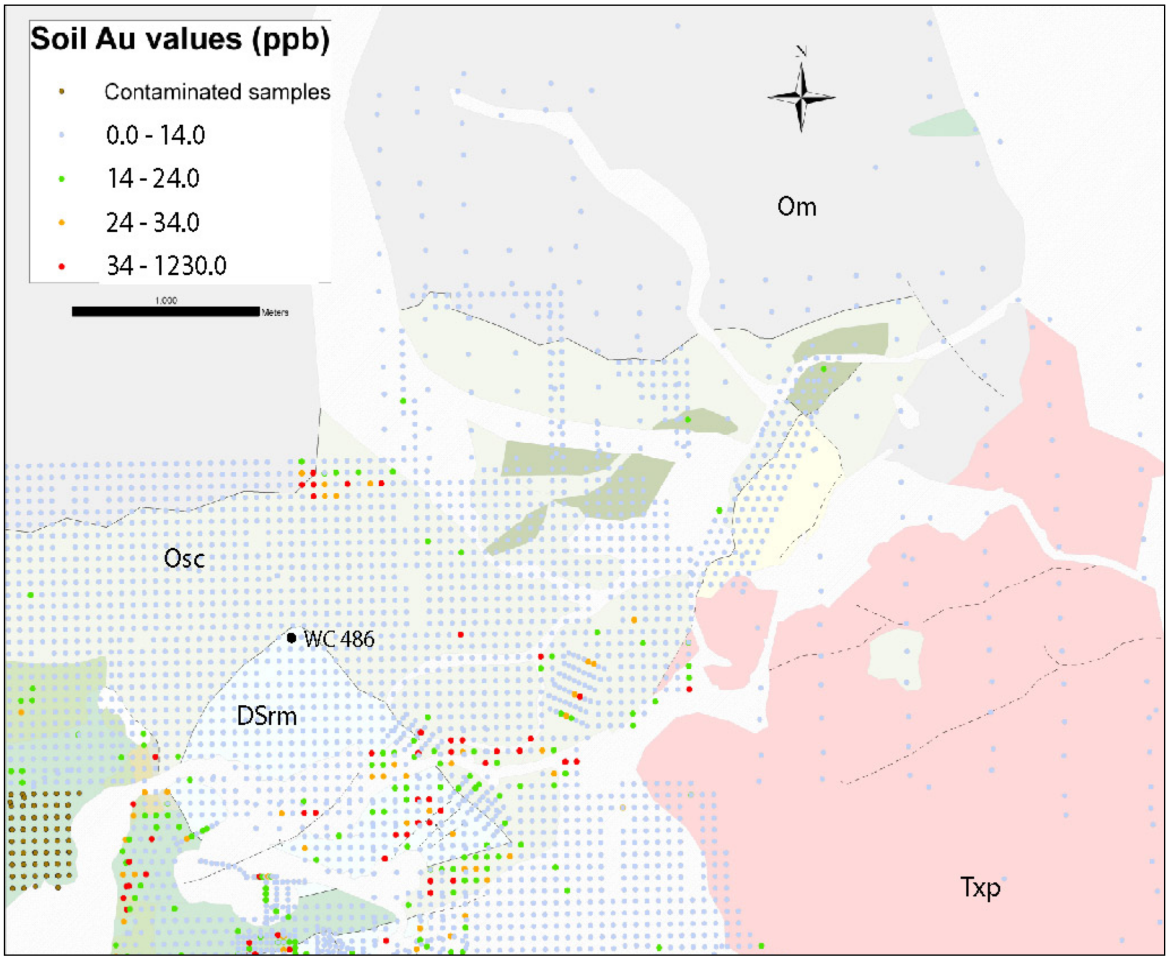

Figure 32. Soil gold values color coded such that grey represents values within the mean plus one standard deviation, green represents samples within two standard deviations, orange within three standard deviations, and red values higher than the mean plus three standard deviations. Drill hole WC 486 encountered 40 ft of mineralization averaging 0.057 opt Au and a 5-ft interval of 0.1899 opt Au.

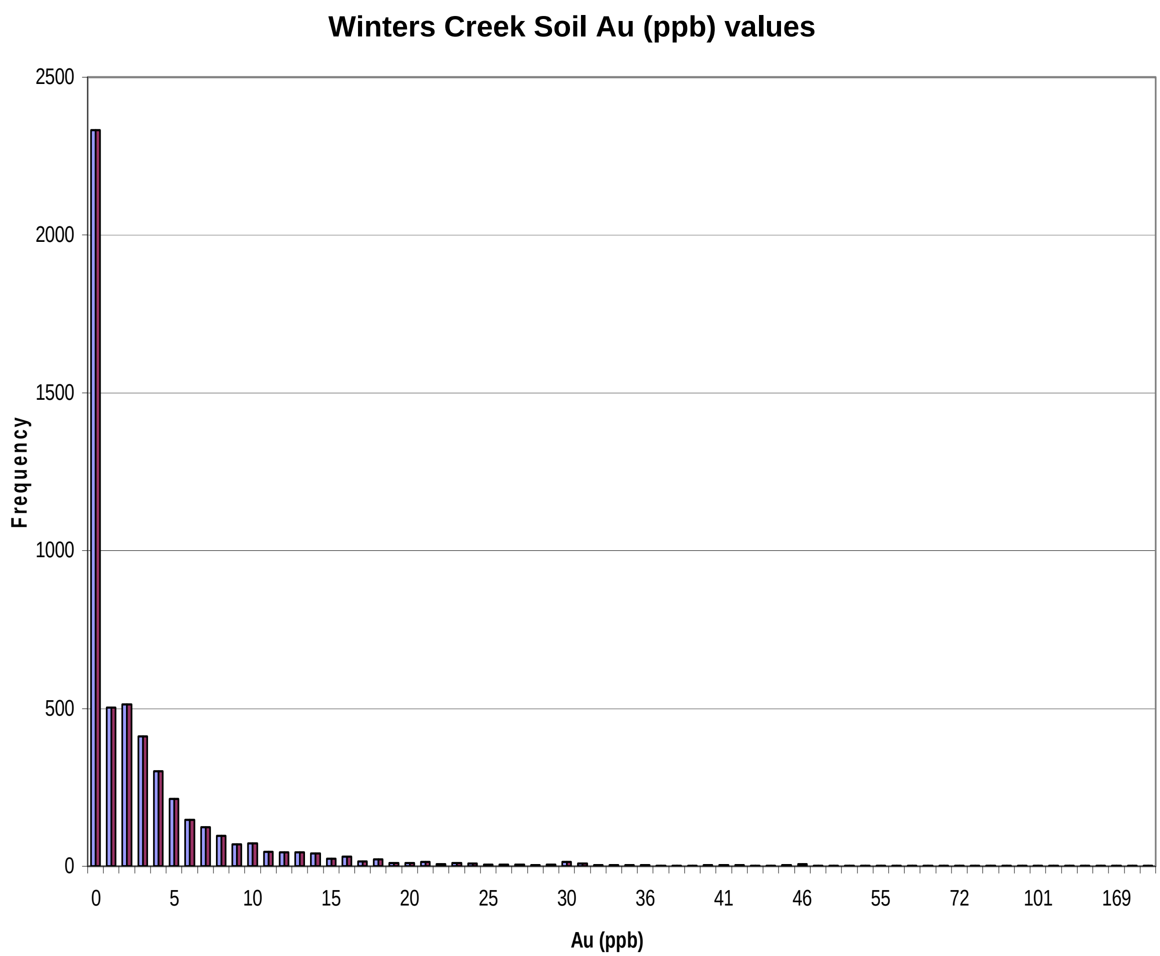

Figure 33. Histogram of soil gold from the Winters Creek area.

The soil samples were also analyzed for arsenic and mercury as these elements are commonly associated with gold in Carlin-type deposits in northern Nevada. The As values, when plotted and color coded (Fig. 34) in the same manner as the Au values, reveal a much higher percentage of soil samples with As values higher than the mean plus one standard deviation. There are significantly more anomalous As samples near and within the McAfee Quartzite than there are anomalous Au samples. Moreover, the locations in the Snow Canyon Formation with anomalous Au values also have anomalous As values. However, when the soil Hg values are plotted and similarly color coded (Fig. 35), there are few soil samples with mercury values higher than the mean plus one standard deviation. Nonetheless, the extensive colluvial cover, soils, and the thick upper plate rocks make it difficult to assess the gold potential at depth.

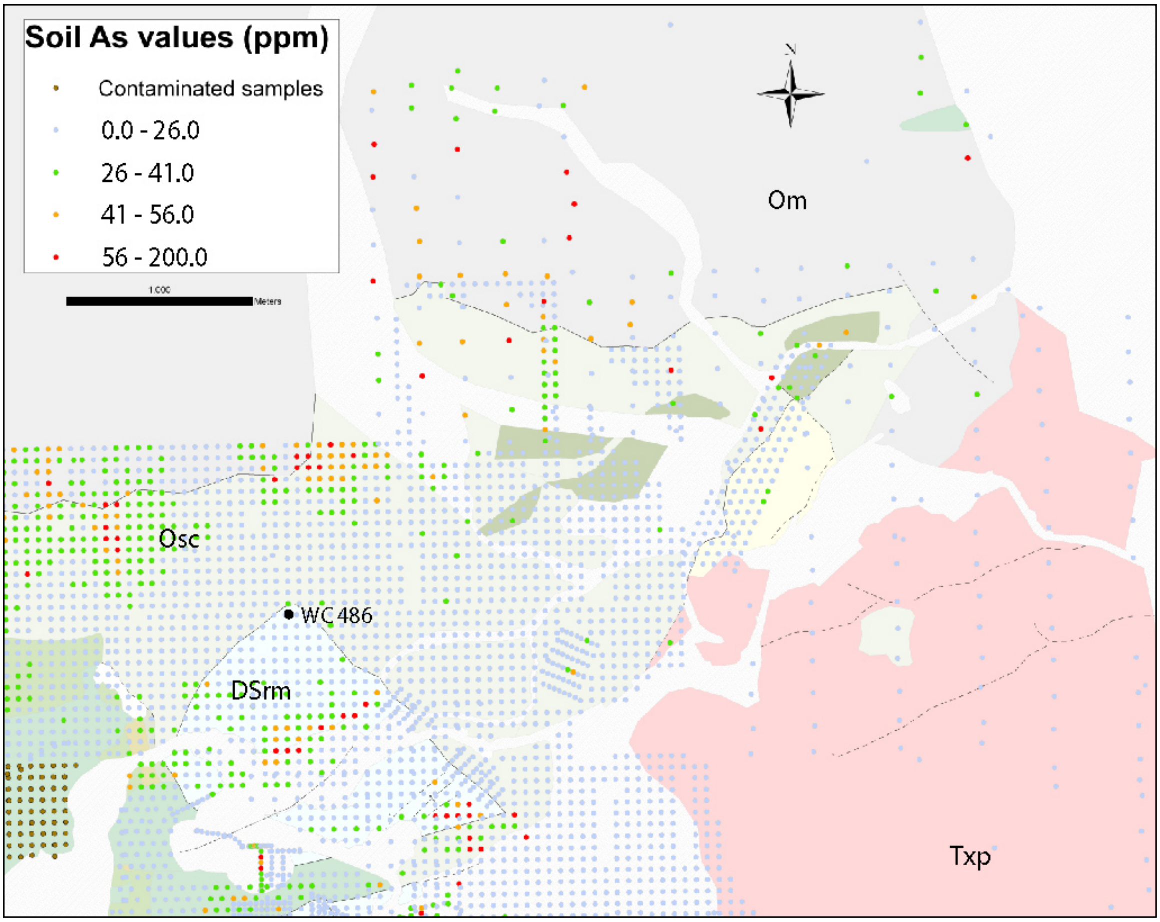

Figure 34. Soil arsenic values color coded such that grey represents values within the mean plus one standard deviation, green represents samples within two standard deviations, orange within three standard deviations, and red values higher than the mean plus three standard deviations.

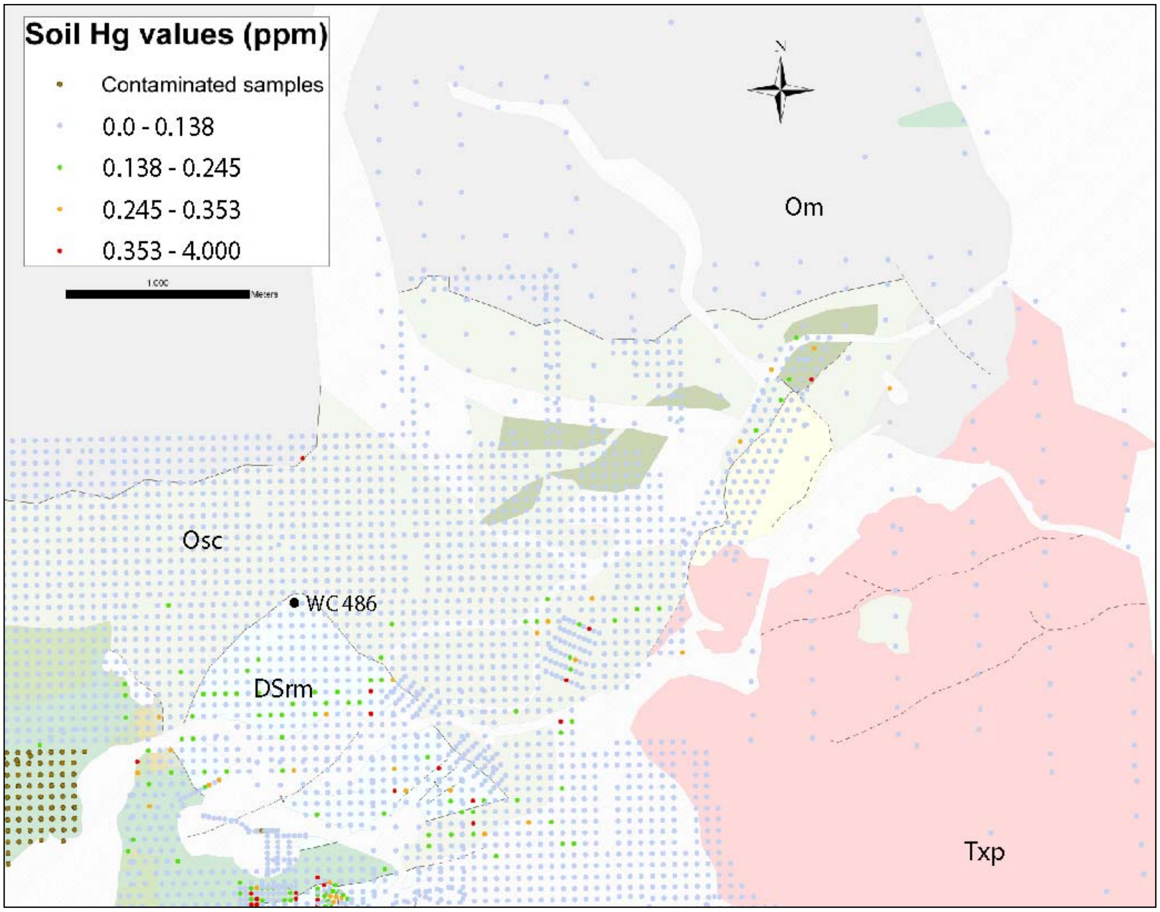

Figure 35. Soil mercury values color coded such that grey represents values within the mean plus one standard deviation, green represents samples within two standard deviations, orange within three standard deviations, and red values higher than the mean plus three standard deviations.

Discussion

The area north of the Winters Creek gold deposit contains both eastern autochthonous assemblage silty carbonates, the Devonian Roberts Mountains Formation, as well as western siliciclastic marine sediments, the Ordovician Snow Canyon Formation and the Ordovician McAfee Quartzite. The Snow Canyon Formation and the McAfee Quartzite, members of the Valmy Group, were thrust over the eastern autochthonous facies during the Devonian-Mississippian Antler Orogeny. In depositional to locally fault contact with the western assemblages is a volcanic sequence comprised of Eocene age volcanic sedimentary rocks, plagioclase-biotite ash-flow tuffs and plagioclase-biotite-hornblende ash-flow tuffs.

The prevailing structural grain in the area trends east to northeast, a prime example being the N70E trending Deadman's Spring Anticline, which was the principal control on mineralization in the Winters Creek gold deposit; however, there is also a northwest striking structural trend. In the Roberts Mountains erosional window, there are abundant high angle faults, associated with strongly developed breccias, dissolution, and collapse, which offset older thrust faults. Though elsewhere in the district structural features, particularly the mineralized northwest and northeast striking features, can have associated soil geochemistry anomalies, it is difficult to identify such a relationship in the Winters Creek area.

One of the objectives of this study was to assess the potential for additional mineralized rocks north of the Winters Creek open pit. As previously discussed, there are no clear soil geochemistry anomalies that are focused along structures that would indicate mineralization. An alteration overprint was not evident in the outcrops or float, with the exception of chalcedony flooding in the Snow Canyon chert along the fault contact with the Mill Site volcanic sequence. The chalcedony flooding may have resulted from fluid flow during the faulting. Thus, there are no soil anomalies along structures or alteration halos to indicate mineralization in Winters Creek. That said, soil samples near WC 486 (see Fig. 32, 33, 34 and Plt. 3), a reverse circulation drill hole which encountered 40 ft of mineralization averaging 0.057 opt and containing a 5-ft interval of 0.1899 opt Au, do not have anomalous Au, As, or Hg values, which may suggest there are other locations in the lower or upper plate rock with mineralized rock at depth and no apparent soil anomaly. A recommendation would be to undertake further soil sampling around WC 486 as well as step-out drilling to better define the extent of mineralized rock in that corner of the lower plate, erosional window and perhaps clarify why there is no apparent soil anomaly.

Looking within the erosional window, there has been significant drilling along the strike of the Deadman's Spring anticline. Some of the drill holes along the northeast projection of the anticline did encounter mineralized rock (Fig. 36). However, these zones were predominantly in Hanson Creek units II, III, and IV, while in the Winters Creek open pit the zones were in the overlying Roberts Mountains Formation. This change in the mineralization suggests a possible change in fluid flow or in

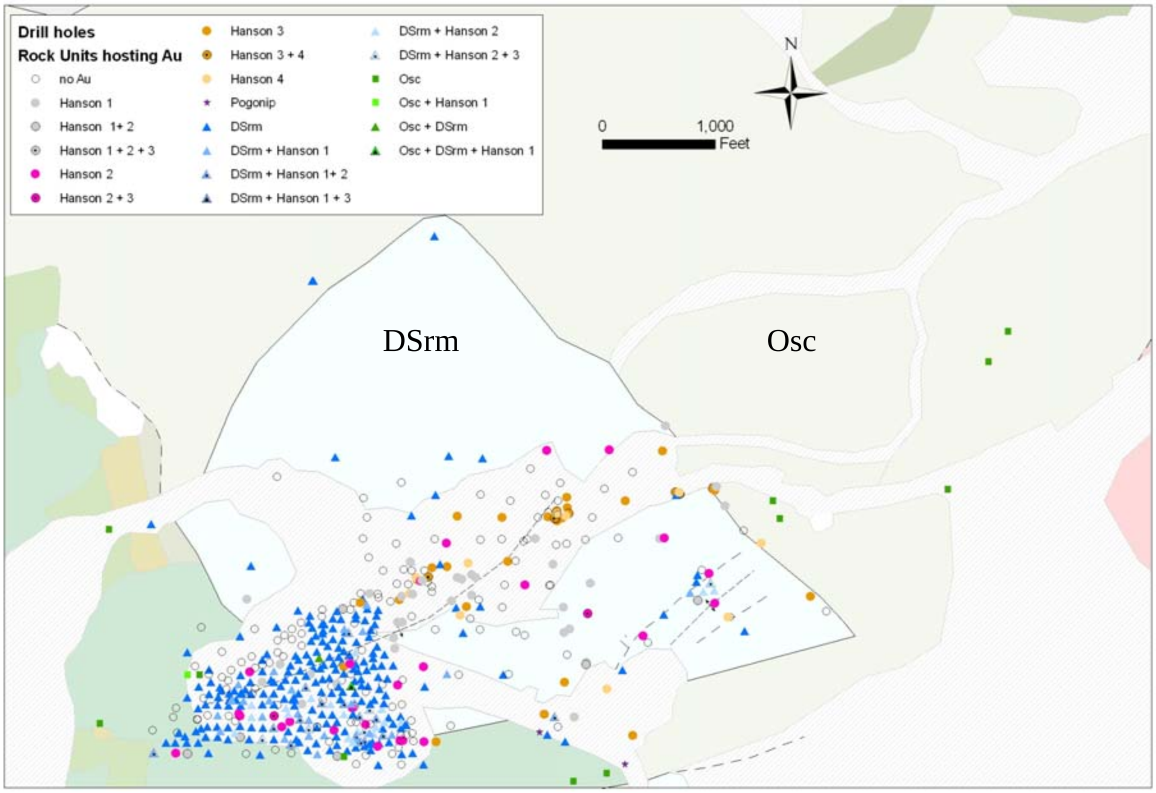

Figure 36. Drill holes that encountered mineralized rock.

favorable host rock. Analysis of the total foot-ounces in each drill hole (Fig. 37) reveals that the amount of mineralized rock, in general, decreases away from the Winters Creek deposit and that Hanson Creek III generally contains more foot-ounces than the other Hanson Creek units. However, the northern portion of the erosional window remains relatively untested. Where drilled, grades ranges from 0-5 foot-ounces and are hosted once again in the Roberts Mountains Formation. Perhaps further drilling in the northern portion of the window is warranted, particularly step-out drilling from holes that did encounter ore grades or anomalous gold values.

It is also possible that the lower plate rocks continue north, stratigraphically below the Snow Canyon Formation. The contact as shown on the map may represent the location at which the Roberts Mountains Formation dips below the Snow Canyon Formation. A recommendation would be to dig a trench or drill north of the known thrust contact in the Snow Canyon, in particular, drilling or trenching near outcrops of greenstone since the greenstone is generally located in the lower portion of the Snow Canyon Formation. Such testing would better define the local stratigraphy, and possibly broaden the known extent of the favorable eastern assemblage rocks.

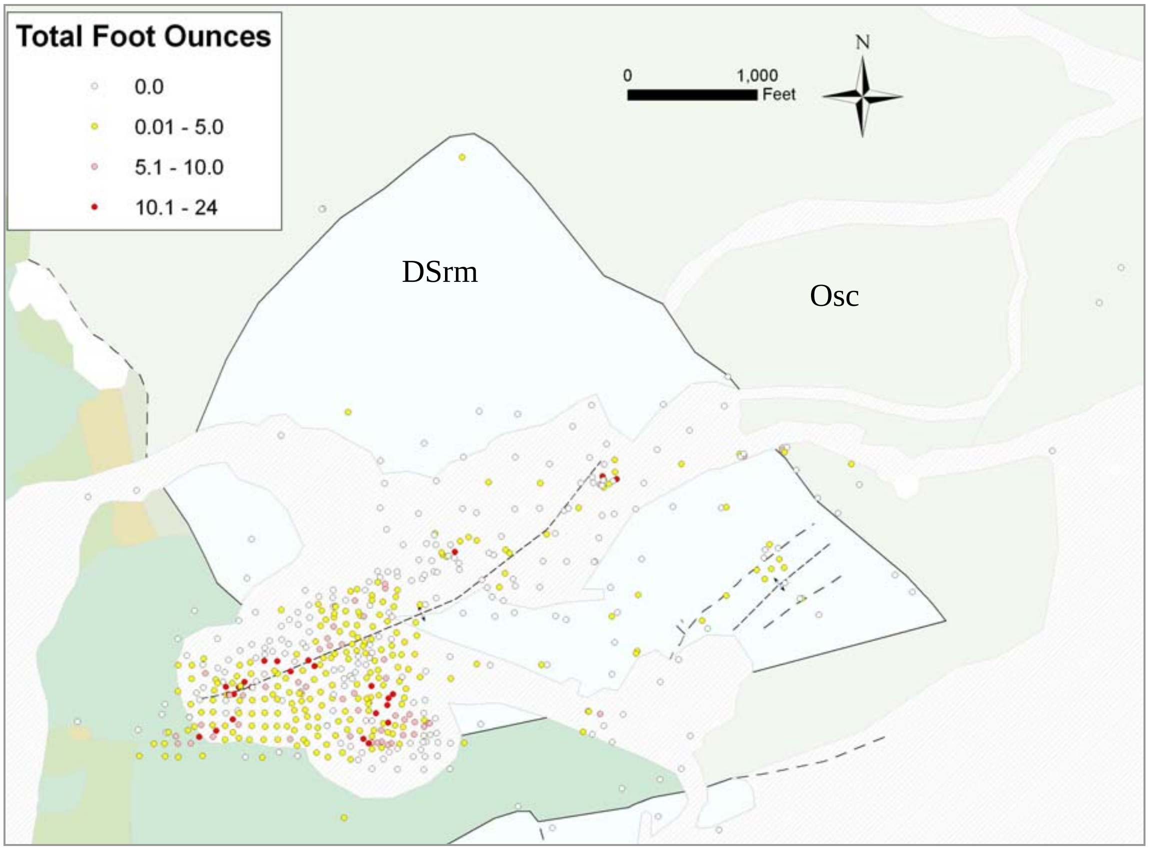

Figure 37. Total foot-ounces found in each drill hole.

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Plate 1. Geologic Map of Winters Creek, Jerritt Canyon District, Elko County, Nevada.

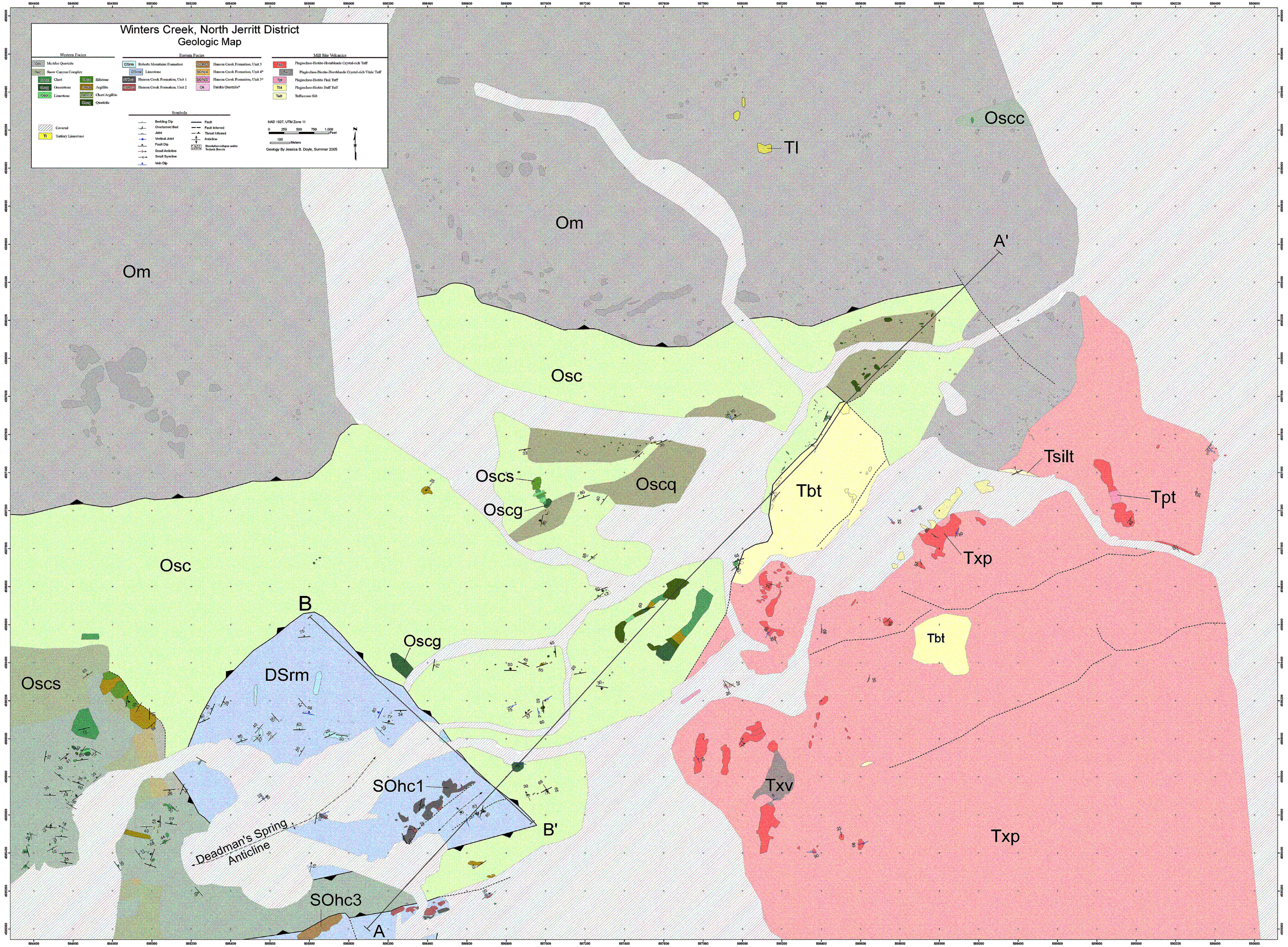

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Plate 2.

Geologic cross section through Winters Creek along transect A-A' (symbols same as Plt. 1).

Jessica B. Doyle July 2007

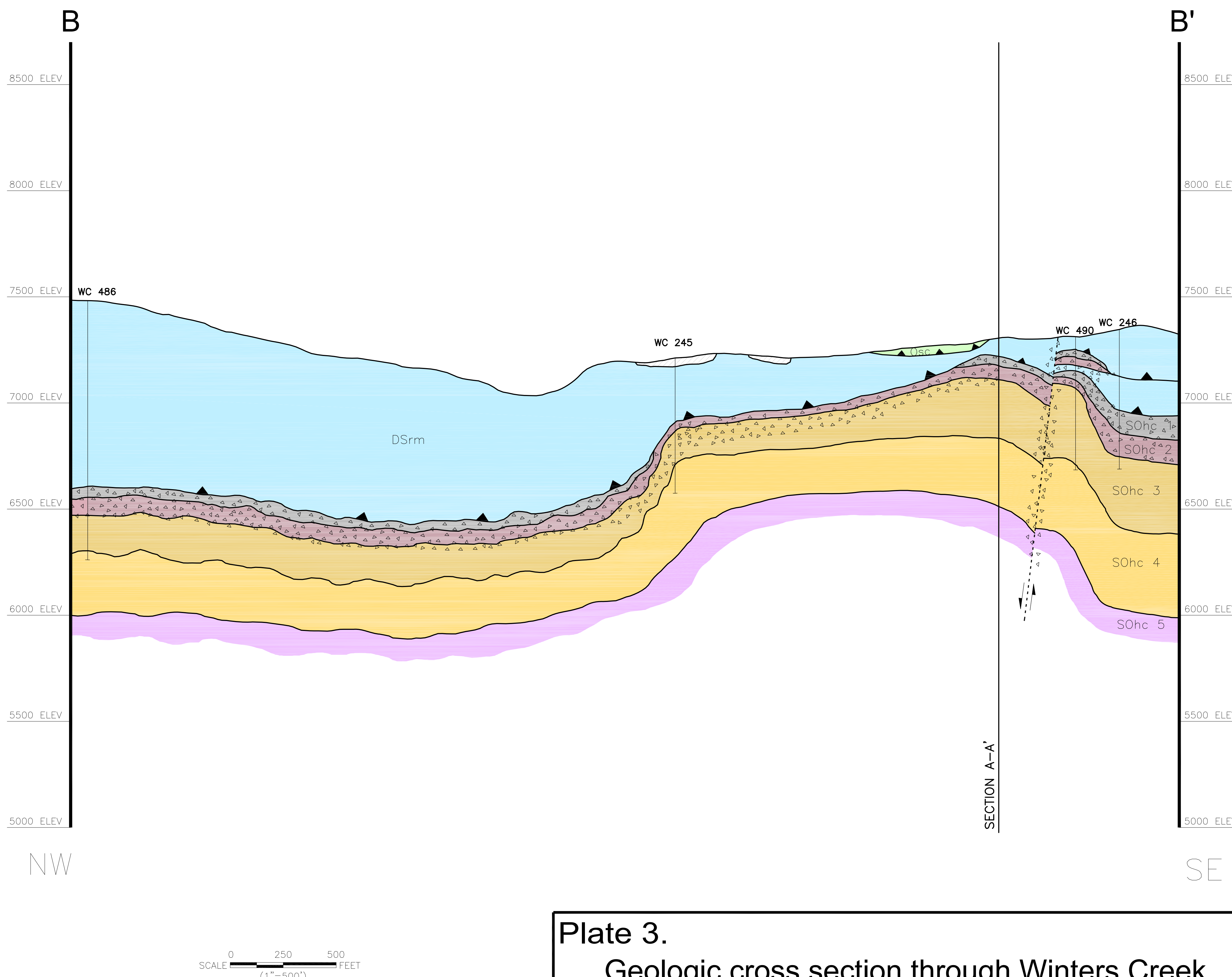

Plate 3.

Geologic cross section through Winters Creek along transect B-B' (symbols same as Plt. 1).

Jessica B. Doyle July 2007