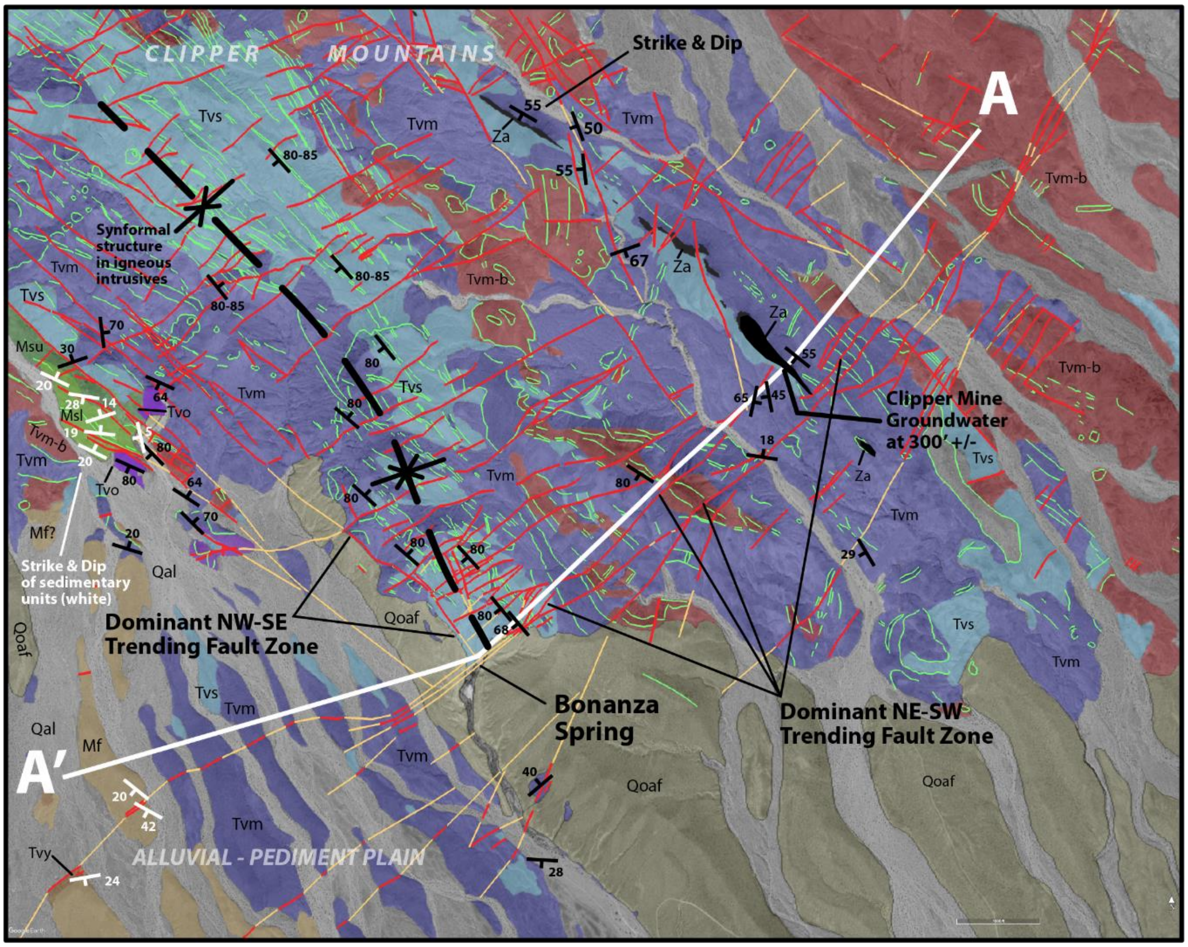
Updated Assessment of Cadiz Water Project's Potential Impacts to Bonanza Springs



Prepared for Cadiz, Inc.

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January 2018

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CADIZ

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ES1.0 Executive Summary

This report presents an update to previous assessments of the potential for adverse impacts by the Cadiz Valley Water Conservation, Recovery and Storage Project (Water Project) on the Bonanza Spring, a natural spring located in San Bernardino County, California's Western Clipper Mountains. This report includes a new detailed geologic evaluation of Bonanza Spring by Dr. Miles Kenney, Ph.D., of Kenney GeoScience and follows an extensive evaluation of springs in the watershed's tributary to the project area that was included with the Final Environmental Impact Report (FEIR) for the Water Project, approved and certified in 2012. This new report further demonstrates that any changes in groundwater levels related to Water Project operations will be limited to the alluvial aquifer where the pumping would occur and will not impact the discharge of the Bonanza Spring. This conclusion was reached based on evidence that the spring's discharge is localized within a fractured rock system that is hydraulically separated from the alluvial regional groundwater system in Fenner Valley located three miles to the east.

The field work and analysis provided in this report also demonstrates that the perennial spring discharge is controlled by the existence of two bounding faults and by long-term average groundwater recharge in the spring catchment area that extends over 4 miles north of the Bonanza Spring. Recharge to the catchment area is tied to infiltration of precipitation and runoff in drainages that are dependent on long-term climate conditions rather than regional groundwater conditions in Fenner Valley.

Despite the adoption of the FEIR, an independent evaluation by San Bernardino County and adoption of a Groundwater Management, Monitoring and Mitigation Plan (GMMMP) and the subsequent judicial validation of these reviews, and without reference to new supporting data nor supporting technical review of the existing data, opponents of the Water Project have continued to allege that the Water Project will have an adverse impact on Bonanza Spring and the flora and fauna in its vicinity. Additionally, a 2016 survey of springs in the Mojave Desert conducted by Andy Zdon and funded by the US Bureau of Land Management and the Nature Conservancy, entitled "MOJAVE DESERT SPRINGS AND WATERHOLES: Results of the 2015-16 Mojave Desert Spring Survey Inyo, Kern, San Bernardino and Los Angeles Counties, California," in a brief, cursory discussion left open questions about the potential for the Water Project to adversely impact Bonanza Spring. For the avoidance of doubt, an in-depth analysis of Bonanza Spring was initiated. Specifically, Dr. Miles Kenney was engaged by Cadiz, Inc. to develop a detailed understanding of the geology of the Bonanza Spring area, which would aid in understanding the hydrogeologic conditions that have given rise to the occurrence of the spring: 1) why the spring is where it is and, 2) how the spring functions and whether it is related to the Alluvial Aquifer in the Fenner Valley.

Dr. Kenney with Kenney GeoScience, and Mr. Foreman, with TLF Consulting, LLC, completed a literature review of springs in the region, including Zdon's 2016 survey in addition to geologic maps and reference reports. Dr. Kenney spent six field days observing lithologic units, fracturing, faulting and other structures. Dr. Kenney and Mr. Foreman also visited the Clipper Mines, located approximately one mile east-northeast of the Bonanza Spring and reviewed literature concerning historical mining operations. Dr. Kenney prepared geologic maps and cross-sections in the Bonanza Springs area to document his findings and conclusions about the geologic conditions in the area of the spring, as presented in this report. Dr. Kenney contributed to a review of Mr. Zdon's geologic interpretation of the occurrence of the Bonanza Spring and the potential impacts of the Cadiz Water Project operations on the spring, which is presented in Kenney and Foreman (2018).

A site visit to the Bonanza Spring was completed on December 13, 2017 to share the initial findings and demonstrate the physical conditions that gave rise to their findings with other experts in geology, hydrology and hydrogeology. The site visit was attended by Dr. John Sharp, Jr., Dr. Charles Groat, Dr. Dennis Williams, Dr. Toby Moore, Will Halligan, Tim Parker, Andrew Stone, Mark Wildermuth, Anthony Brown, and Brian Villalobos.

ES 1.1 Geologic Setting

Numerous geologic units were identified during this study that span the last 1.7 billion years. Most of the rocks exposed in the Western Clipper Mountains are associated with igneous activity related to Miocene extensional tectonics; however, younger and older rocks occur as well. The most detailed work done on igneous rocks in the area is that of Miller et al. (USGS, Bulletin 2160, 2007, Plate 1) which provided a detailed geologic mineral evaluation along the northern-most flanks of the Clipper Mountains and north of the Clipper Mountains. An attempt to correlate units identified in this study with those of the Miller et al. (2007) study was conducted. These correlations assisted in the understanding that most of the igneous activity in the study area likely occurred after deposition of the Peach Tree Tuff dated at 18.5 Ma. In addition, the attempt to correlate with map units of Miller et al. (2007) strongly suggest that the Western Clipper Mountains likely exhibit the largest aerial extent of Miocene age subvolcanic igneous intrusive rocks (emplaced at shallow depths) in the region. These units are described as shown in Figure ES-1.

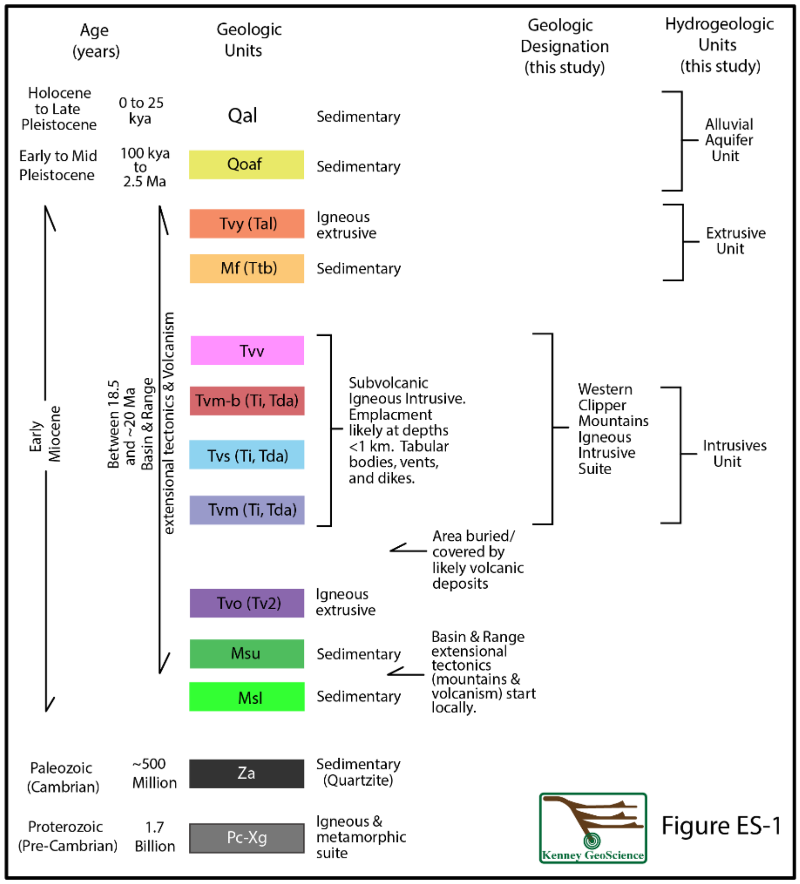


Figure ES-1 Stratigraphic Units and designation of the western Clipper Mountains

Bonanza Spring occurs at the southern limit of a 4 to 5 mile long and 1.5 mile wide region of nearly 100 percent bedrock exposures of the Western Clipper Mountains Igneous Intrusive Suite (Figure ES-2). These bedrock exposures are across the entire western Clipper Mountains. In this region, the igneous member contacts (i.e. Tvm-b, Tvm and Tvs), dikes and igneous emplacement structures within the Western Clipper Mountains Igneous Intrusive Suite, all trend northwest to southeast, essentially cumulating in the southwestern Clipper Mountains at the Bonanza Spring.

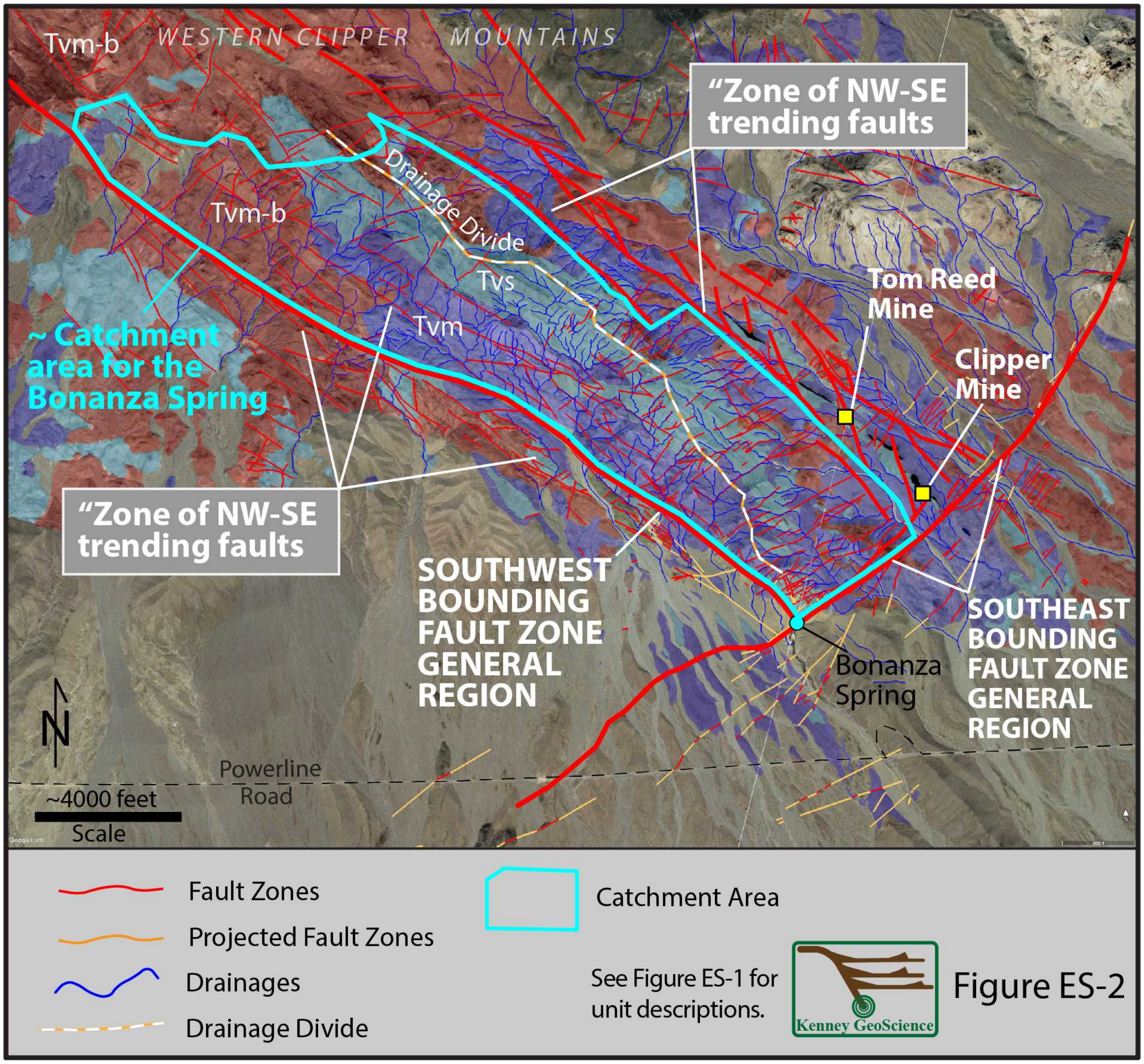


Figure ES-2 Bonanza Spring Catchment area and pertinent Geologic features

Faulting in the Western Clipper Mountains Igneous Intrusive Suite exhibit modal areas where the faults generally trend northeast-southwest within unit Tvs, and northwest-southeast in the bounding units Tvm-b and Tvm. However, there is an over three mile long prominent northeast-southwest trending fault zone that occurs from the Pediment Plain all the way across the southeastern limits of the entire region mapped as the Western Clipper Mountains Igneous Intrusive Suite (Figure ES-2). This fault zone is exposed in washes located along the southeastern boundary of the spring and exhibits an over 15 to 20-foot thick sheared-gouge zone of highly jointed, sheared and fluid altered rocks. This fault zone is referred to herein as the Southeastern Bounding Fault Zone. In addition, there is a relatively prominent northwest-southeast trending fault zone along the southwestern limit of the Bonanza Spring referred to as the Southwest Bounding Fault Zone (Figure ES-2). The Southwest and Southeast Bounding Fault Zones intersect at the Bonanza Spring.

Faults within the Western Clipper Mountains Igneous Intrusive Suite are identified near the Bonanza Spring as groundwater barriers. Hence, in terms of fault structures, the Bonanza Spring occurs at the intersection of two relatively prominent fault zones both of which exhibit evidence of being groundwater barriers. In addition, there is a zone of northwest to southeast trending faults to the east of the Bonanza Spring, which also appear to represent a barrier to groundwater flow. Groundwater encountered in gold mines (Tom Reed and Clipper Mine, see Figure ES-2) indicate groundwater levels significantly lower (about 1950 feet elevation) than groundwater levels at the spring (2100 feet elevation), demonstrating the effect of this fault zone.

ES 1.2 Hydrogeology of the Bonanza Spring Area

There are three principal hydrogeologic units in the Bonanza Spring area, which are identified in Figure ES-1. The three units include a sedimentary unit and two crystalline rock units as follows: 1) the combined younger and older alluvium (map symbols Qal and Qoaf), referred to in Section 3 simply as the Alluvial Aquifer Unit, 2) Extrusive Volcanic Unit (combine map units Tvy and Mf) and, 3) Intrusives Unit (map symbols Tvm-b, Tvs, and Tvm). The characteristics of these units are described in detail in Section 2 herein.

The Intrusives and Extrusive Volcanic Units are characterized by secondary porosity and permeability resulting from faulting and fracturing, as compared to primary porosity and permeability exhibited by the Alluvial Aquifer Unit, which is associated with intergranular pore spaces. The Alluvial Aquifer typically exhibits similar hydrogeologic properties over its thickness; variations are due primarily to variations in texture, e.g., sand and gravel generally are more transmissive than silt and clay. Hydrogeologic properties such as specific yield and transmissivity are a function of fracture density, fracture aperture (i.e., width and roughness), precipitation of minerals within fractures and depth below land surface. In general, porosity and transmissivity of crystalline rocks decrease with depth as fracture density decreases and fracture apertures are closed with the weight of the rock above. Numerous investigators have shown that groundwater production capacities of wells decrease significantly with depth (e.g., Freeze, 1979, Fetter, 1980, and Krasny and Sharp, 2007). Krasny and Sharp (2007) state that, "The upper and middle zones (influenced by weathering and fracturing) can form a regionally extended "near surface aquifer" that is generally conformable to the land surface with a thickness of tens to more than a hundred meters with permeability generally decreasing with depth. This aquifer usually offers the best groundwater abstraction possibilities. However, the thickness and character of this complex and heterogenous aquifer changes spatially in relation to tectonic deformation (faulting and fracturing), lithologic facies, and weathering." Most of these studies suggest that porosity and transmissivity is dramatically reduced below a couple hundred meters (600 to 700 feet).

The likely catchment area for groundwater recharge upgradient of the Bonanza Springs is shown in Figure ES-2. The basis for identifying this catchment area is described as follows:

- The convergence of the two bounding faults, one trending northwest to southeast and the other trending northeast to southwest,
- The western extent of the eastern zone of northwest-southeast striking faults and,
- The upstream extent of the watershed of surface drainages that drain the east-southeast area of Clipper Mountains in the zone defined by the first two items.

The catchment is approximately 2,350 acres. The long-term recharge of this catchment area is estimated from the INFIL3.0 model results presented by CH2M HILL (2010). The average long-term recharge rate is estimated to be approximately 190 acre-feet per year (AFY), which is about eight percent of the total recharge in the Clipper Mountains. Recharge varies year to year depending on precipitation.

As described above, the likely depth of fractured rock is expected to be in the range of 600 to 700 feet below ground surface; below that depth, groundwater flow is anticipated to be a *de minimis* quantity. As described above, groundwater was detected at 300 to 500 feet below ground surface approximately one mile to the east of the Bonanza Spring. Based on these depths, saturated fractured rocks may range from as much as 200 to 400 feet in thickness in the Intrusives Unit, upgradient of the spring. However, the saturated thickness is expected to increase downgradient toward the bounding fault as recharge accumulates and flows downgradient. The storage of groundwater upgradient of the spring may be conservatively estimated using a thickness of approximately 100 feet and a 0.03 specific yield over the thickness of the saturated unit. The volume (V_{gs}) of groundwater in storage above the Bonanza Spring is 7,050 acre-feet (AF) given these values.

Major faults, such as the southern bounding fault at the Bonanza Spring, identified above, serve as barriers to groundwater flow, resulting in mounding behind these barriers. Cross section B-B' (Figure ES-3 and Figure ES-4) extending from above Bonanza Spring, across the northeast-southwest bounding fault, to the Alluvial Aquifer in Fenner Valley, shows the likely pattern of groundwater flow from the Bonanza Spring downgradient to Fenner Valley. Groundwater levels in the Alluvial Aquifer are at 1,100 feet elevation, about three miles downgradient of the Bonanza Spring. Groundwater levels across the bounding fault are likely significantly offset due to the low permeability of the fault zone, which impounds groundwater. On the downgradient side of the fault, groundwater flow is reduced relative to groundwater flow above the fault as the discharging groundwater flow is consumed by the riparian vegetation at the spring. Other faults located downgradient likely result in some mounding of groundwater levels behind them as well, however, there are no observed perennial springs downgradient of the Bonanza Spring. Groundwater moves through fractured zones in the Intrusives Unit toward the Extrusive Unit and Alluvial Unit in Fenner Valley. This fractured zone is likely limited to the upper few hundred feet as fracture apertures typically close with depth and the transmissivity declines significantly as described above. As shown in Figure ES-4, groundwater flow occurs in the Intrusives Unit, the base of which is above the water table of the Extrusive Volcanic Unit/Alluvial Aquifer. Therefore, the flow in the Intrusives Unit is effectively hydraulically separated from the flow in the Extrusive Volcanic Unit/Alluvial Aquifer. Changes in groundwater levels in the Extrusive Volcanic Unit/Alluvial Aquifer will not affect groundwater conditions upgradient in the Intrusives Unit. These findings indicate that changes in groundwater levels in the Alluvial Aquifer from pumping will not affect discharge at Bonanza Spring.

ES1.3 Potential Impacts of the Cadiz Water Project on Bonanza Spring

The hydrogeology of the Bonanza Spring area creates robust conditions for long-term sustainability of the spring. We conclude that the existence of the spring is dependent on long-term average recharge to maintain groundwater levels and storage above the elevation of the spring, where it discharges across the convergent bounding faults.

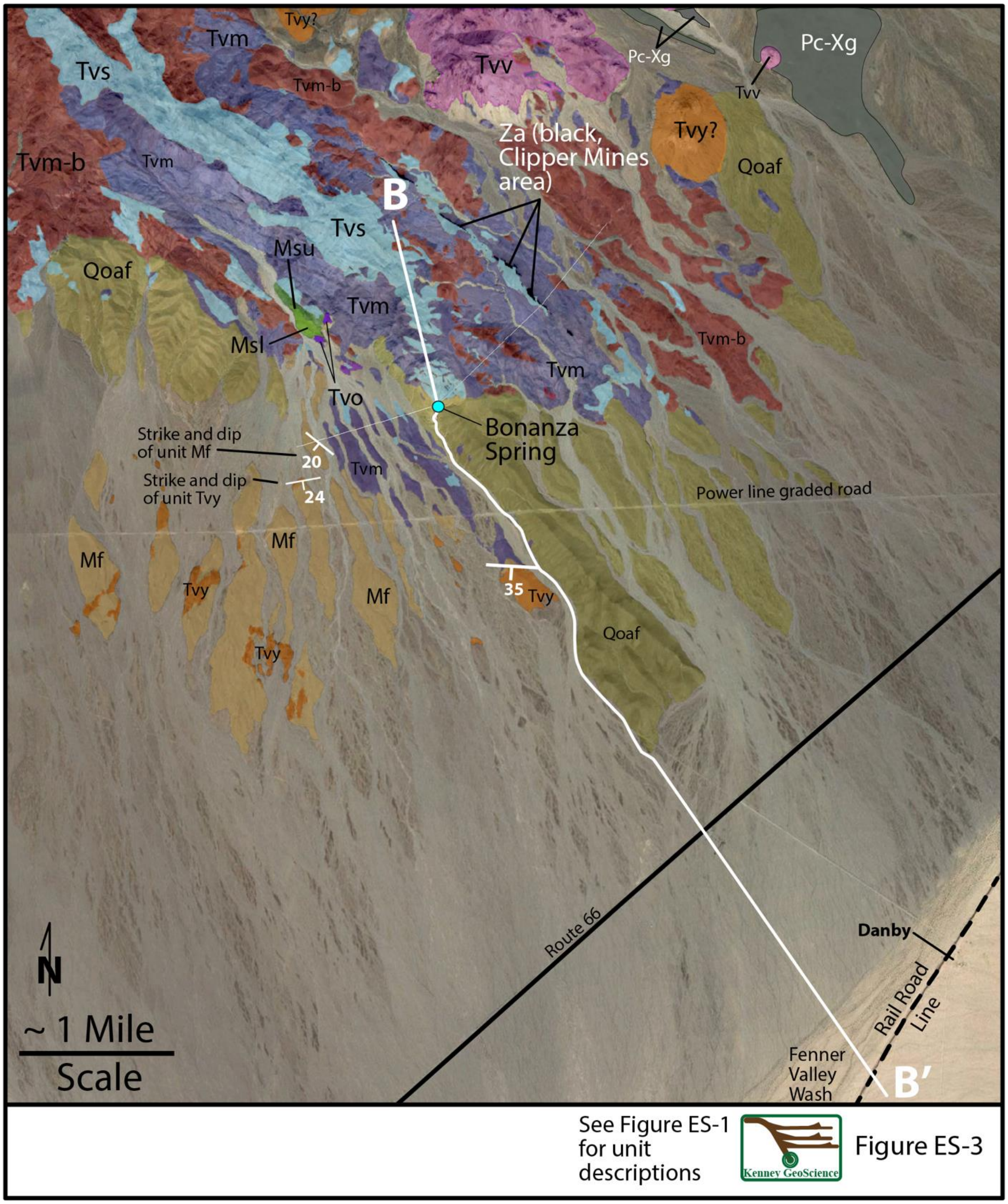


Figure ES-3 Geologic map showing Cross Section B-B' along Bonanza Wash

The Water Project wellfield will operate in and southwest of the Fenner Gap, approximately 11 miles from the Bonanza Spring. The wellfield will extract 50,000 AFY on average, ranging from 25,000 AFY to 75,000 AFY in any given year. Groundwater flow simulations using three-dimensional numerical groundwater flow models of the operation of the Water Project are described in detail in the FEIR (2012). In addition, in an abundance of conservatism, groundwater flow model simulations included a range of recharge rate scenarios to examine potential groundwater-level declines in the Alluvial Aquifer. Recharge rates were varied from 5,000 AFY to 32,000 AFY. The maximum extents of the 20-foot drawdown contour is more than three miles from the spring, as combined from all recharge scenarios. This means that beyond this contour line, drawdown is projected to be less than 20 feet under all recharge rate scenarios simulated using the groundwater flow models.

The drawdown effects will not extend to the spring area due to a hydraulic disconnect between the Intrusives Unit and the Extrusive Volcanic Unit/Alluvial Aquifer unit as described above, as well as the occurrence of faults between the spring area and the Fenner Valley. Consequently, the drawdown effects from the Water Project will be limited to the Alluvial Aquifer.

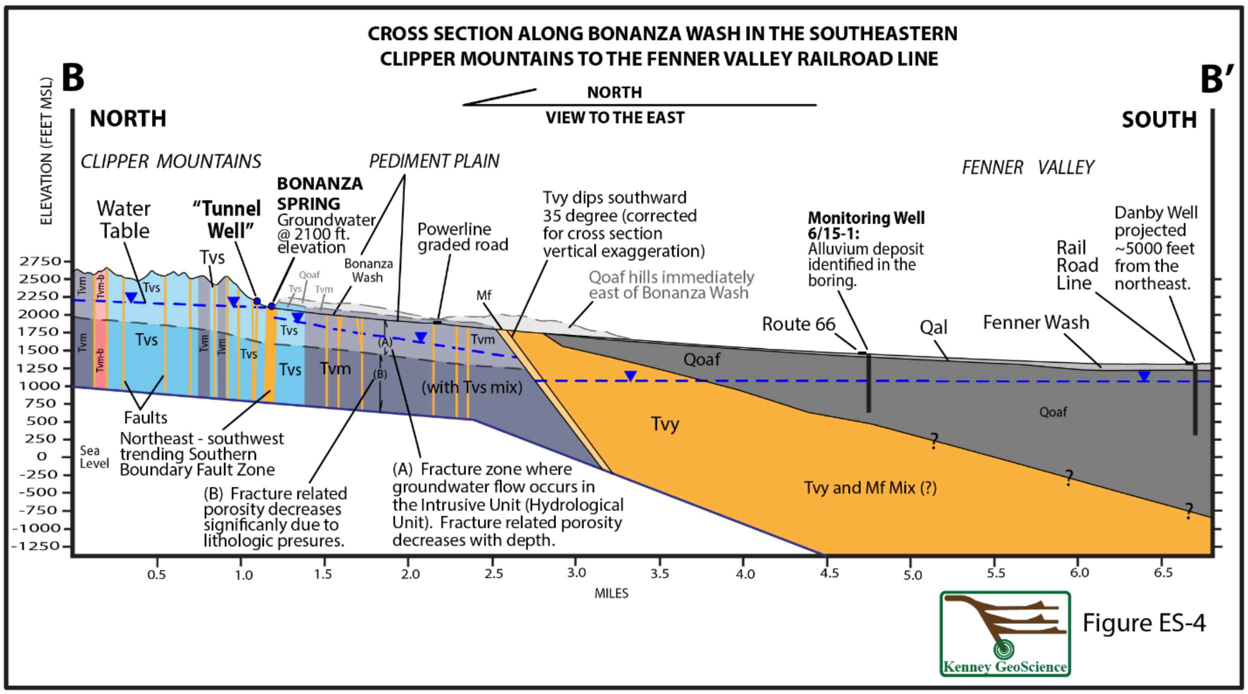


Figure ES-4 Cross Section B-B' along Bonanza Wash from Clipper Mountains to Fenner Valley

1.0 Introduction

This report presents an update to previous groundwater assessments regarding the potential for the Cadiz Valley Water, Conservation, Recovery and Storage Project (Water Project) to pose impacts on the Bonanza Springs, located in the western Clipper Mountains, and includes a detailed geologic evaluation by Kenney GeoScience (i.e. Dr. Miles Kenney). This updated assessment follows an extensive evaluation included with the Final Environmental Impact Report (FEIR) for the Water Project and shows that the pumping from the Water Project, located 11 miles from the spring, will not impact the discharge of the Bonanza Spring, as the spring's discharge is localized within a fractured rock system that is hydraulically separated from the alluvial regional groundwater system in Fenner Valley. Our recent work provided in this report demonstrates that the perennial spring discharge is controlled by the existence of two bounding faults and by long-term average groundwater recharge in the spring catchment area that extends over 4 miles north of the Bonanza Spring, which is tied to infiltration of precipitation and runoff in drainages driven by long-term climate conditions rather than regional groundwater conditions.

1.1 Background

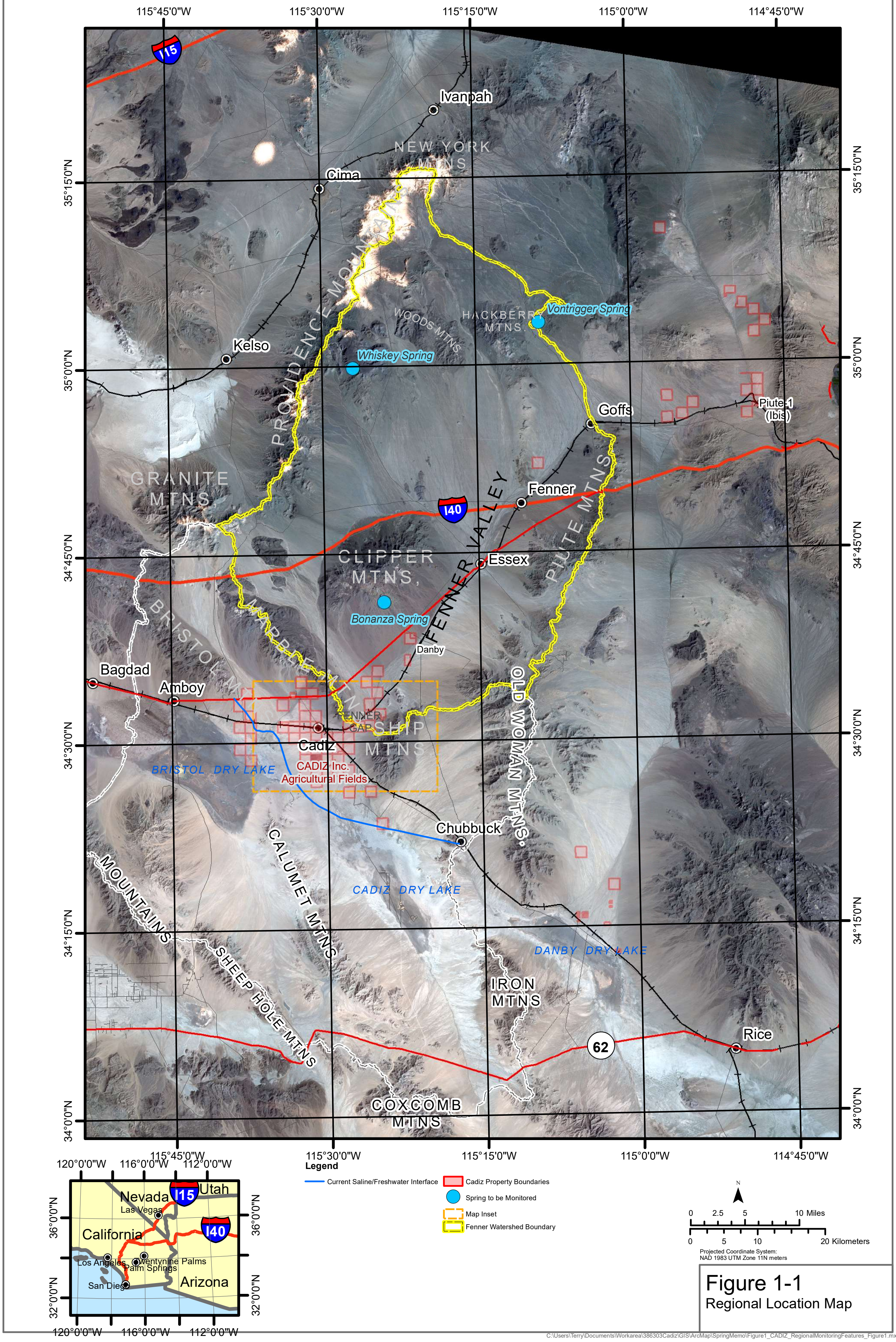
The Water Project is designed to capture an average of 50,000 acre-feet per year (AFY) of groundwater from the Cadiz and Fenner valleys in eastern San Bernardino County, California that is presently migrating to the Cadiz and Bristol Dry Lakes and evaporating. Cadiz Inc. owns approximately 34,000 acres of land in the Cadiz and Fenner valleys. This largely contiguous landholding is located approximately 200 miles east of Los Angeles, 60 miles southwest of Needles, and 50 miles northeast of Twentynine Palms (Figure 1-1). The Cadiz property extends from the northern portion of the Cadiz Valley through Fenner Gap (located between the Marble and Ship mountains), into the southwestern portion of Fenner Valley (Figure 1-1).

Santa Margarita Water District (SMWD), as the Lead Agency for the California Environmental Quality Act (CEQA) compliance, certified the FEIR for the Water Project on July 31, 2012. In addition, San Bernardino County, as a CEQA Responsible Agency, approved the FEIR and the Groundwater Management, Monitoring, and Mitigation Plan (GMMMP) on October 1, 2012. The GMMMP defines specific management, monitoring and mitigation for the Water Project, including pre-operational activities. The GMMMP also provides specific significance criteria for the Water Project (CH2M HILL, 2012).

Substantial geologic and hydrogeologic information was developed and impact analyses were conducted to support the Water Project FEIR. Dr. Miles Kenney (2011) presented findings regarding detailed geologic mapping of the Fenner Gap area. CH2M HILL presented an updated assessment of the recharge to the Fenner and Orange Blossom Wash Watershed areas, as well as an assessment of evaporative discharges from the Bristol and Cadiz Dry Lakes, which included actual evaporation measurements from the dry lakes by the Desert Research Institute. Geosciences Support Services, Inc. conducted detailed groundwater flow and solute transport modeling, including subsidence, to assess potential impacts to groundwater levels, groundwater quality, and land subsidence. Dr. David Groeneveld completed an assessment of potential impacts to vegetation and potential for dust generation in the project's vicinity due to lowered groundwater levels. These assessments are included in the FEIR: Appendix E2, Fugitive Dust and Effects from Changing Water Table at Bristol and Cadiz Playas; Appendix F4, Vegetation, Groundwater Levels and Potential Impacts from Groundwater Pumping near Bristol and Cadiz Playas; and Appendix H, Hydrology Reports. These assessments represent the most up-to-date evaluation of groundwater conditions for the area.

As a component of the FEIR, CH2M Hill (2011) also conducted an assessment of the effects of the Water Project operations on springs, with a focus on the closest springs, especially the Bonanza Spring, located in the Clipper Mountains, approximately 11 miles from the proposed Water Project wellfield and more than 1,000 feet higher in elevation.

Figure 1-1 Regional location map



CH2M HILL concluded that there is no information demonstrating a physical connection of any identified springs in the local mountains to groundwater in the alluvial aquifer where the Water Project's pumping would occur. Consequently, because no hydraulic connection between the springs and the regional groundwater system in the Fenner Valley was identified nor does a connection likely exist, the assessment concluded that the Water Project would not likely have any impact on springs.

The 2011 report also presented an analysis assuming the existence of hydraulic continuity between the groundwater that feeds the springs and the groundwater in the alluvial aquifer for an additional level of analytical conservatism and to further address concerns expressed during the EIR comment period. The results of this more conservative assessment demonstrated that for many reasons, including: distance between drawdown in the alluvial aquifer and springs, change in elevation, required low transmissivity of fractured bedrock, and hydraulic connectivity, that in the highly unlikely event of any hydraulic continuity, any changes in spring discharge would be very minor and most likely within the range of natural climatic variability.

The Groundwater Stewardship Committee (2011) reviewed the CH2M Hill (2011) assessment and stated the following:

"*The springs in the watershed area rely on rainfall recharge of shallow fractured bedrock, and there is no evidence that the springs are dependent on the deep alluvial groundwater system from which the Project proposes to pump groundwater or that they will be affected in any way by the pumping. All of the springs are more than 11 miles away and are located in fractured crystalline (granitic and metamorphic) rocks at substantially higher elevations than the alluvial aquifer from which the Project wells will pump groundwater. Therefore, pumping in the alluvial aquifer in the Project well field should not affect groundwater levels in these crystalline rocks, so it will not adversely impact springs. Nevertheless, the GSC supports ongoing observation of the springs and the flow conditions as proposed, including the closest spring (Bonanza Spring), and several more distant springs (such as Whiskey and Vontrigger) for comparison and to account for climatic changes.*"

The GMMMP for the Water Project is comprehensive and includes regular monitoring of the Bonanza Springs, as well as the Whiskey and Vontrigger springs prior to, during, and post Water Project operations. This monitoring has already commenced.

1.2 Scope of Work

The Water Project completed an environmental review and permitting process in accordance with CEQA from 2010 – 2016. This process included the 2012 approval of the FEIR by SMWD and San Bernardino County's independent evaluation, approval, and adoption of the GMMMP as a CEQA responsible Agency, as well as the 2014 and 2016 judicial validation of these reviews and approvals by California's Courts. However, questions from opponents about the Water Project's potential to harm Bonanza Spring have persisted in the public domain. Recently, opponents have cited a 2016 survey of springs in the Mojave Desert prepared by Andy Zdon, which in a brief, cursory overview of Bonanza Spring alleges Water Project operations could adversely impact its water supply.[1] For the avoidance of doubt and to respond to questions left open by project opponents, Cadiz engaged Dr. Miles Kenney Ph.D. last year to develop a detailed analysis of the geology of the Bonanza Springs area, which would aid in

[1] Zdon, Andy, MOJAVE DESERT SPRINGS AND WATERHOLES: Results of the 2015-16 Mojave Desert Spring Survey Inyo, Kern, San Bernardino and Los Angeles Counties, California, 2016.

understanding the hydrogeologic conditions that have given rise to the occurrence of the spring: 1) why the spring is where it is and, 2) how the spring functions.

Dr. Kenney with his firm Kenney GeoScience, and Mr. Terry Foreman of TLF Consulting, LLC completed a literature review of springs in the region, including a recent report issued in Zdon's 2016 Survey as well as available geologic maps and reference reports.[2] Dr. Kenney spent six days in the field making observations of lithologic units, fracturing, faulting and other structures at and around Bonanza Springs. Dr. Kenney and Mr. Foreman also visited the Clipper Mines, located approximately one mile east-northeast of the Bonanza Spring and reviewed literature about these historical mining operations. Dr. Kenney prepared geologic maps and cross-sections in the Bonanza Springs area to document his findings and conclusions about the geologic conditions in the area of the spring, as presented in this report. Dr. Kenney also contributed to a review of Mr. Zdon's geologic interpretation of the occurrence of the Bonanza Spring, as briefly described in the 2016 Spring Survey, which is presented in this report.

A further site visit to the Bonanza Spring led by Dr. Kenney and Mr. Foreman was completed on December 13, 2017 during which they presented their findings to independent experts in geology, hydrogeology and hydrology. This group included Dr. John Sharp, Jr., Dr. Charles Groat, Dr. Dennis Williams, Dr. Toby Moore, Will Halligan, Tim Parker, Andrew Stone, Mark Wildermuth, Anthony Brown, and Brian Villalobos. Following the December 13 site visit Dr. Sharp, Dr. Williams, Mr. Parker, Mr. Brown and Mr. Wildermuth provided peer review assessments of the conclusions of this report.

The conclusions of this report are briefly summarized in the Executive Summary above and provided in detail within the body of the report.

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[2] Zdon also prepared a report about the hydrology of the Cadiz Valley area for Center for Biological Diversity and other conservation organizations submitted during the EIR commend period.

2.0 Geologic Setting

The Clipper Mountains are located in the Basin and Range Geomorphic Province (BRGP), which is characterized by a series of structural and topographic basins and bounding mountain ranges. The BRGP exists throughout Nevada, eastern and southeastern California, and western to southern Arizona. The alternating mountains and valley topography primarily resulted from extensional (pulling apart) tectonics that occurred during the Miocene (see Wernicke, 1992) that resulted in both relatively linear and in places domal shaped mountain ranges similar to that of the Clipper Mountains.

Most valleys within the BRGP are truly basins in the sense that sediments eroding from the local mountain ranges deposit relatively locally within the immediate valley. Streams remain trapped within the BRGP basins and do not terminate to the Pacific Ocean or Gulf of California (Sea of Cortez). Drainages for the Clipper Mountains flow to Fenner Valley, which is unusual in that it represents a subsurface groundwater basin at depth, but surface flow and upper groundwater flow is able to flow westwards into the Cadiz Valley.

The rocks of the Clipper Mountains range in age from 1.7 billion years old Proterozoic metamorphic and igneous rocks to recent surficial alluvium. However, the vast majority of the rocks of the Clipper Mountains are associated with Miocene age intrusive and extrusive volcanism related to basin and range extensional tectonics. Most of the volcanism in the Clipper Mountains occurred between 23 and 18.5 million years ago (Ma) which represents the early stages of Miocene age extensional tectonics and associated volcanism.

Throughout the study area, which focused in the western and southwestern Clipper Mountains, abundant small-scale faults and relatively high-density jointing/fracturing occur in the volcanic rocks. Most of the volcanic rocks near and to the north of the Bonanza Spring are subvolcanic, indicating that they were emplaced at shallow depths of likely less than one mile. Therefore, these rocks were once buried by likely other igneous rocks and to a lesser degree sedimentary rocks. The overlying “burial” rocks and additional volcanic extrusive rocks were deposited over much of the southwestern Clipper Mountains that were subsequently eroded away causing extensive exposure of the igneous subvolcanic intrusive rocks over most of the western and southwestern Clipper Mountains.

2.1 Geologic Units of Western Clipper Mountains

Numerous geologic units were identified during this study that span the last 1.7 billion years. Most of the rocks exposed in the western Clipper Mountains are associated with igneous activity associated with Miocene extensional tectonics; however younger and older rocks occur as well. Unfortunately, no publications were identified for this study that provided detailed descriptions, ages and correlations of the igneous rocks exposed in the western and southwestern Clipper Mountains. The most detailed work done on igneous rocks in the area is that of Miller et al. (USGS, Bulletin 2160, 2007, Plate 1) which provided a detailed geologic mineral evaluation along the northern most flanks of the Clipper Mountains and north of the Clipper Mountains. An attempt to correlate units identified in this study with those of the Miller et al. (2007) study was conducted. These correlations assisted in the understanding that most of the igneous activity in the study area likely occurred prior to deposition of the Peach Springs Tuff which Neilson et al. (1990) determined to be 18.5 Ma (Neilson et al, 1990). In addition, the attempt to correlate with map units of Miller et al. (2007) with geologic units in the study area strongly suggest that the western Clipper Mountains likely exhibit the largest aerial extent of Miocene age subvolcanic igneous intrusive rocks (emplaced at shallow depths) in the region.

The stratigraphy of the western Clipper Mountains determined for this study is described below from youngest to oldest (Figure 2-1).

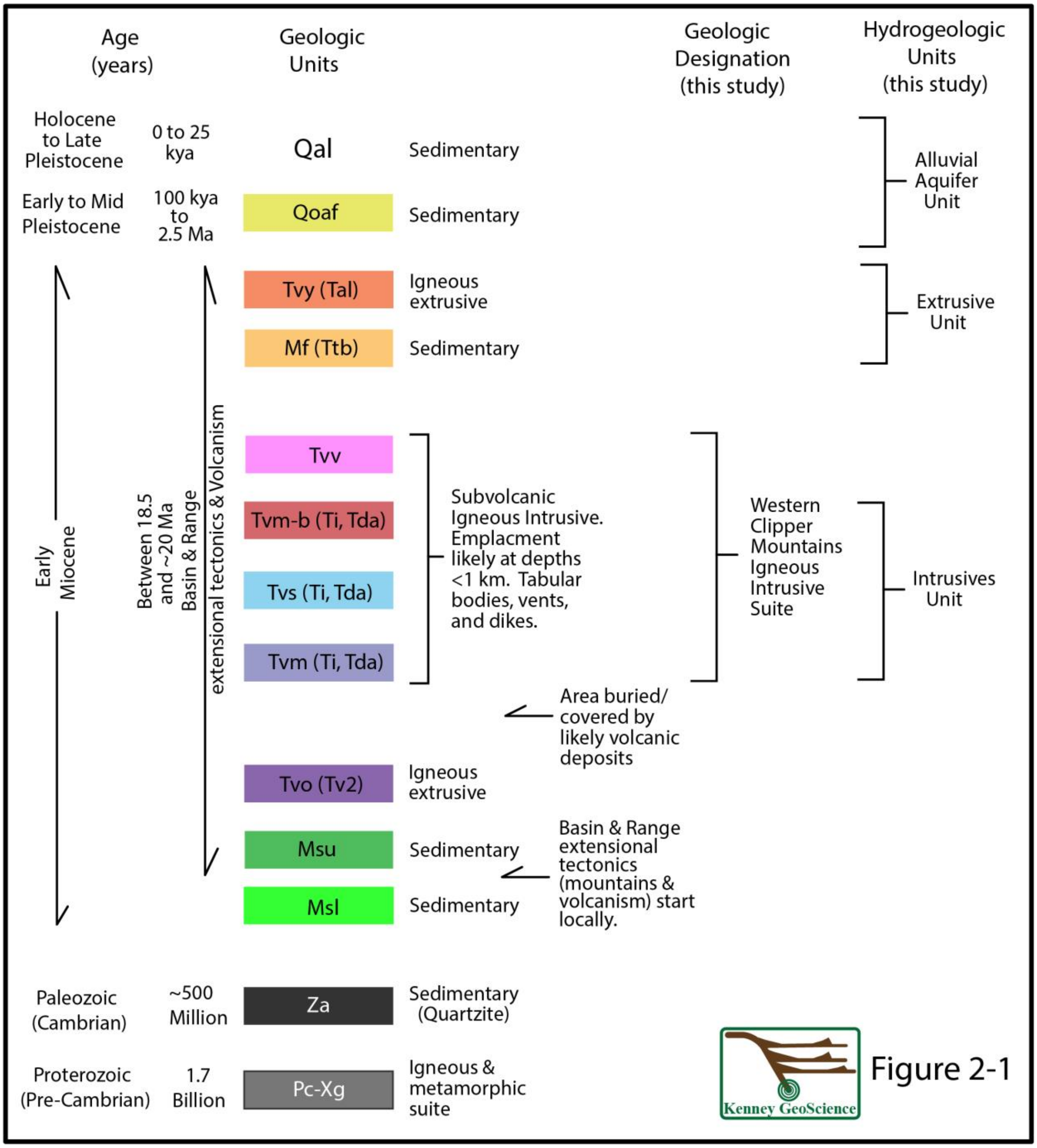


Figure 2-1 Stratigraphic units and designation of the western Clipper Mountains

2.1.1 Qal-Quaternary Alluvium

Quaternary alluvium occurs along flanks of the Clipper Mountains within washes and low relief bar and swale geomorphic areas. Most of unit Qal was likely deposited during the past several hundred thousand years. This unit was not mapped in detail (not subdivided), but is observed locally to be a relatively thin unit and deposited on an unconformity with underlying older units of primarily Miocene in age. The underlying Qal contact represents a pediment erosional surface indicating that older units occur at very shallow depths of typically less than 5 to 10 feet across much of the alluvial plain west of the Bonanza Spring (Figure 2-2). This region is referred to herein as the Pediment Plain. Unit Qal is composed of mostly gravel and sand derived from the local Clipper Mountains. Of note, clasts of lower Cambrian Zabriskie Quartzite occur quite commonly in particular canyons suggesting outcrops of Zabriskie Quartzite may occur in areas not yet formally identified. No clasts of other Paleozoic sedimentary rocks were identified other than possibly the lower Cambrian Cadiz Formation.

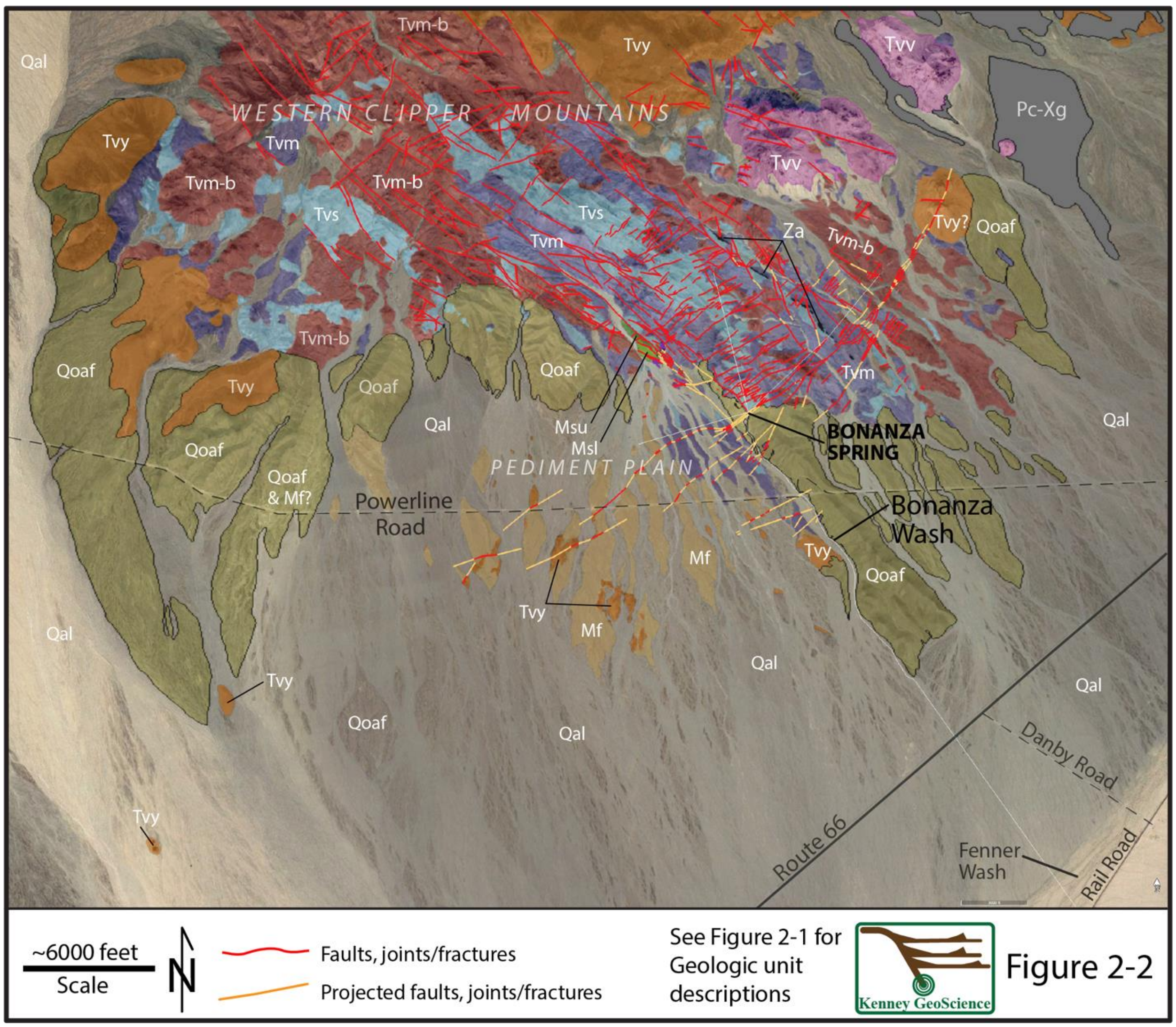


Figure 2-2 Geologic map of the western Clipper Mountains

2.1.2 Qoaf-Quaternary Older Alluvium

Quaternary older alluvium is identified along portions of the flanks of the western Clipper Mountains (study area). Unit Qoaf likely deposited during the early Pleistocene, but it is possible that some higher and more dissected members may be as old as late Pliocene (i.e. 2.5 to 3 Ma) due to their tall topographic relief of greater than 250 feet, induration, and clast weathering. The unit consists of very coarse grained fanglomerates (debris flows) with clast compositions dominated by local Miocene igneous rocks of the western Clipper Mountains and some boulder size clasts of Zabriskie Quartzite. Unit Qoaf typically does not exhibit a stratigraphic thickness equal to its relief from the local adjacent washes and the top of unit Qoaf. This conclusion is based on the observation of Miocene age rocks (mostly igneous intrusives) identified along the flanks of local Qoaf exposures. Although exposed as rolling hills along the flanks of the Clipper Mountains, unit Qoaf occurs at depth and with considerable thickness underlying unit Qal in the Fenner Valley to the south. Hence, unit Qoaf was deposited during a time of higher topographic relief exhibiting taller mountains ranges and topographically lower valley floors.

2.1.3 Tvy (Tal)-Miocene Younger Volcanic Igneous Extrusives

Unit Tvy represents a sequence of igneous volcanic extrusive rocks that are relatively younger than all other igneous rocks in the study area. Locally, unit Tvy consists of basalt flows and volcanic breccias. The volcanic breccias are composed of zones of indurated "welded" material and other areas of poorly consolidated and strongly jointed volcanic debris that have led to the near surface erosional features such as vugs.

In the study area, this unit is identified as small exposures across the Pediment Plain as massive volcanic breccias and basalt flows that generally dip between 25 and 36 degrees to the south (Figure 2-2). A thick sequence of unit Tvy can be observed from the Bonanza Spring area as it is well exposed as a series of steep southward facing slopes along the crest of the Clipper Mountains to the north. Other exposures occur along the western flanks of the Clipper Mountains and across the Pediment Plain (Figure 2-2). Unit Tvy is presumed to be interbedded with unit Mf (described below) as both units were identified across western and southern Pediment Plain; however, the contact of these two units was not directly identified in the field. These data suggest that unit Tvy, and interbedded unit Mf (described below) were deposited across the entire western Clipper Mountains and have subsequently been eroded away leading in part to deposition of unit Qoaf. Hence, units Tvy and Mf were likely the primary burial unit on top of the intrusive igneous rocks (described below) extensively exposed at Bonanza Spring and north of the Bonanza Spring (Figure 2-2).

Unit Tvy exhibits a paucity of secondary weathering mineralization and weathering compared to relatively older Western Clipper Mountains Igneous Intrusive Suite that includes units Tvv, Tvm-b, Tvs and Tvm described below. This includes nearly no calcite, iron, and quartzite mineralization along joints and faults, and penetrative epidote secondary mineralization as observed in older igneous rock units. However, the massive volcanic breccia members of unit Tvy identified immediately west of Bonanza Spring Wash and in the northern Pediment Plain area exhibit large erosional vugs that are over six feet in diameter and 5 to 10 feet deep (Photographs of these outcrops in report Section 3). The origin of the vugs is not completely understood, but may have resulted from less cohesive zones within unit Tvy developed during their original deposition.

Unit Tvy is in part, correlated with unit Tal of Miller et al. (2007), which they map along the northern flanks of the Clipper Mountains. Miller et al. (2007) describe their unit Tal as air-fall tuff (silicic rhyolites) and lava flows, and that mafic basalt flows form the uppermost part of the unit. This description is consistent with visual observations and aerial mapping during this project identifying light colored "silicic" rocks near the base and dark to black colored "mafic" rocks near the top of the stratigraphic section of exposures of unit Tvy along southward facing slopes north of Bonanza Spring.

2.1.4 Mf (Ttb)-Miocene Fanglomerates & Alluvial Deposits

Unit Mf consists primarily of massive and poorly bedded fanglomerates composed primarily of clasts eroded from the local Miocene age igneous rocks. This description is based a series of small exposures of unit Mf across the western and southern Pediment plain primarily with wash cut banks. The clasts are generally pebble to cobble size and commonly highly weathered in-situ. The matrix is composed of finer grained silt and sand. Where identified across the Pediment Plain area, unit Mf exhibits dips of 20 to 42 degrees to the southwest and south, similar to dip magnitude and direction of unit Tvy (Figure 2-7a below). Alternating small exposures of unit Mf and Tvy suggest that the two units are interbedded. Units Mf and Tvy are deposited on top of the Western Clipper Mountains Igneous Intrusive Suite that includes units Tvv, Tvm-b, Tvs and Tvm. Hence, unit Mf and Tvy occur at shallow depths across the western and southwestern Pediment Plain as compared to units Tvv, Tvm-b, Tvs and Tvm in the northeastern Pediment Plain.

2.1.5 Western Clipper Mountains Igneous Intrusive Suite (Units Tvv, Tvm-b, Tvs, and Tvm)

The western Clipper Mountains Igneous Intrusive Suite includes four units: Tvv, Tvm-b, Tvs and Tvm. The majority of the volume of these units were all emplaced at shallow crustal depths of likely less than 1 mile. This type of igneous emplacement and cooling depth are referred to as hypabyssal or subvolcanic. Unit Tvv is an outlier in the sense that it is located outside the primary focus area of this study and is of limited aerial extent as it formed as a series of relatively circular vents (Figure 2-2). However, unit Tvm-b, Tvs and Tvm are all similar in that they were emplaced, at least in part, as a series of northwest-southeast trending tabular bodies similar to an igneous dike, but much thicker than what is generally considered an igneous dike (of tens to possibly hundreds of feet thick). It is possible that units Tvm-b, Tvs and Tvm were emplaced via similar mechanisms as igneous dikes with subsequent injections running roughly parallel to earlier emplacements.

Rocks of the Western Clipper Mountains Igneous Instrusive Suite may correlate with units Ti and Tda of Miller et al. (2007) that they map primarily in the Granite Mountains located approximately 20 miles northwest of the Bonanza Spring. Miller et al. (2007) mapped a unit referred to as “Shallow-intrusive rocks (Miocene)” with label Ti in the southern Granite Mountains. Their unit Ti appears to be northwest-southeast trending dikes, which is the same trend as that identified for the Western Clipper Mountains Igneous Intrusive Suite (Figure 2-2). Map unit Tda of Miller et al. (2007) is labeled “Dacite and Rhyolite (Miocene)” occurring in the southern most Granite Mountains. They describe unit Tda as thin lava flows and associated domes of intermediate composition. Hence, their unit Tda exhibits both extrusive and intrusive igneous members. Kenney (2011) identified hypabyssal (subvolcanic) rocks along the northwestern Ship Mountains where the magma was postulated to have emplaced along fault zones (unit Tvi). This interpretation suggests that the northwest-southeast trending emplacement zone of units Tvm-b, Tvs and Tvm may have originated as a basin and range extensional fault zone.

Units of the Western Clipper Mountains Igneous Intrusive Suite are described below.

2.1.5.1 Tvv-Miocene Vent Igneous Intrusives

Unit Tvv occurs in the eastern portion of the study area as a series of subvolcanic vents associated with ancient volcanoes that have eroded away (Figure 2-2). Although this unit was not mapped via a site visit, but by aerial imagery (Google Earth Pro), its light color suggests the unit is silicic (i.e. Rhyolite) in composition. The unit appears to have emplaced into the other Western Clipper Mountain Igneous Intrusive Suite units (Tvm-b, Tvs and Tvm) described below, suggesting a relatively young age.

2.1.5.2 Tvm-b (Ti, Tda)-Miocene Mafic Igneous Intrusives

Unit Tvm-b is a relatively more mafic member of the Western Clipper Mountains Igneous Intrusive Suite and most of the unit is likely basaltic in composition. The unit was injected via a series of tabular bodies some of which swelled to approach circular shaped vents structures. Aerial image mapping indicates that in places, members of unit Tvm-b may exhibit volcanic flows based on possible "bedding" layers; however, these structures may just represent crystallization structures with vent systems. Unit Tvm-b may correlate with units Ti and Tda mapped by Miller et al. (2007) identified in the Granite Mountains to the northwest.

2.1.5.3 Tvs (Ti, Tda)-Miocene Silicic Igneous Intrusives

Unit Tvs is more silicic than units Tvm-b and Tvm of the Western Clippers Mountains Igneous Intrusive Suite. Unit Tvs was emplaced as a series of northwest-southeast tabular bodies. Its exposures also trend approximately northwest-southeast along a topographic high from the Bonanza Spring toward the northwest across the western Clipper Mountains (Figure 2-2), a distance of approximately four miles (Figure 2-2). Where mapped in the field, unit Tvs is only weakly weathered with the exception of relatively strong secondary weathering and mineralization in close proximity to the Bonanza Spring (Figure 2-5). Unit Tvs is primarily bounded on the southwest and northeast by unit Tvm (Figure 2-2). Unit Tvs may correlate with units Ti and Tda mapped by Miller et al. (2007) identified in the Granite Mountains to the northwest.

2.1.5.4 Tvm (Ti, Tda)-Miocene Mafic-Silicic Igneous Intrusives

Unit Tvm has an igneous "intermediate" composition between mafic and silicic (andesite to dacite) and represents a series of igneous emplacements that generally trend northwest to the southeast similar to units Tvm-b and Tvs. Unit Tvm occurs in dominantly two northwest-southeast trending zones that occur on either side of unit Tvs (Figure 2-2). Hence, unit Tvm is the most common unit to be in contact with unit Tvs along the northwest-southeast trending exposures of these units in the western Clipper Mountains (Figure 2-2). Outside of this system of rocks toward the northeast and southwest, unit Tvm is primarily in contact with unit Tvm-b (Figure 2-2).

Where mapped in the field, unit Tvm appeared to exhibit some gentle member dips suggesting the unit may be partially extrusive. However, these structures are interpreted to represent internal flow and crystallization structures at subvolcanic cooling depths. Unit Tvm may correlate with units Ti and Tda mapped by Miller et al. (2007) identified in the Granite Mountains to the northwest.

2.1.6 Tvo (Tv2)-Miocene Older Volcanic Igneous Extrusives

Unit Tvo was identified via field mapping in a small area at the base of the western Clipper Mountains and northern portion of the Pediment Plain (Figure 2-2). The unit was identified in close proximity to units Msu and Msl suggesting they are of similar age. Unit Tvo is composed of mafic flows (basalts) and exhibit very unusual large oval shaped "blebs" of strong secondary epidote mineralization and purple discoloration associated with hydrothermal fluid migration. The magnitude of the secondary mineralization and the paucity of epidote mineralization in other igneous units evaluated in this study suggests that unit Tvo is an older unit. Heat generated by the emplacement of the Western Clipper Mountains Igneous Intrusive Suite may have assisted in driving hydrothermal fluids within older units such as Tvo. Simply based on age, unit Tvo correlates with unit Tv2 of Miller et al. (2007).

2.1.7 Msu and Msl-Miocene Sedimentary Rocks Upper & Lower Members

Units Msu and Msl represent a distinctive sedimentary unit identified near exposures of unit Tvo. Both units exhibit alternating and well-defined beds of siltstone and sandstone with minor gravel that are very well indurated (very dense). The unit was deposited in a fluvial environment exhibiting coarse grained channels and finer grained overbank deposits. However, the upper member is interbedded with volcanic breccias and flows and the sedimentary units contain some Miocene age volcanic clasts. In contrast, the lower member did not exhibit any volcanic members or clasts. These observations suggest that unit Msl was deposited prior to local basin and range extensional tectonism (mountain building) and associated volcanism, and unit Msu was deposited at the onset of local basin and range extensional tectonism and volcanism. This interpretation indicates that units Msu and Msl are the oldest identified units associated with Miocene extensional tectonism.

2.1.8 Za-Cambrian Zabriskie Quartzite of the Clipper Mines

Unit Za is the Zabriskie Quartzite, an early Cambrian metamorphosed sandstone that was deposited across a large region of the southwestern United States. It is part of a series of early to late Paleozoic sedimentary-metamorphic rocks exposed in nearby mountain ranges that have a potential stratigraphic thickness of over 6000 feet (Kenney, 2011). However, the Zabriskie Quartzite that was the only early Cambrian unit observed in the western Clipper Mountains — with the possible exception of a small outcrop of the early Cambrian Cadiz Formation in the northern Pediment Plain. Unit Za was identified as an erosionally resistant, northwest-southeast trending ridge east of the Bonanza Spring (Figure 2-2). Mines from the early 1900's are associated with the Za outcrop including the Tom Reed and Clipper Mines (Figure 2-6a and Figure 2-6b).

2.1.9 Pc-Xg-Proterozoic Igneous and Metamorphic Suite

Unit Pc-Xg represent Proterozoic igneous and metamorphic rocks of approximately 1.7 billion years. Regionally, the unit is dominated by gneiss and granitoids. Unit Pc-Xg outcrops along the flanks of the southwestern Clipper Mountains (Figure 2-2) and along the eastern flanks of the Clipper Mountains (Miller et al., 2007). Hence, these rocks occur beneath the entire Clipper Mountains with the exception of where Miocene intrusives occur. In terms of structural geology, all igneous extrusive units would be deposited above unit Pc-Xg; however, all igneous intrusive units would have cut through unit Pc-Xg as their magma was migrating toward the surface.

2.2 Geologic Structures

Pertinent geologic structures in the western Clipper Mountains include fractures/joints, faults, and igneous intrusive features that include dikes and emplacement contacts.

2.2.1 Fractures and Joints

High density fracturing and jointing, typically in the form of nearly 3-dimensional, orthogonal conjugate systems occur in all the Miocene age rocks. Hence, the joint systems result in creating cubic clasts associated with two joint modes dipping nearly vertical and at 90-degrees to one another, the other joint mode being closer to horizontal. However, the near vertical joints are generally more abundant. High density jointing on the scale of one to four inch spacing is particularly the case for unit Tvs as the density of jointing in units Tvm-b and Tvm is relatively less, but still present.

In many places, secondary mineralization occurs along the joints, which is commonly composed of calcite or quartz. However, generally, most joints and fractures are relatively clean and do not exhibit significant secondary mineralization.

2.2.2 Faulting

Abundant relatively small-scale faults were identified throughout the Miocene age igneous rocks (Figure 2-2 and Figure 2-6a). The highest density of faulting is observed in the Western Clipper Mountains Igneous Intrusive Suite (Figure 2-2 and Figure 2-3). Via field mapping, faults were observed exhibiting less than a few inches of apparent strike-slip displacement to tens of feet. In addition, nearly all the faults identified via field mapping exhibited near vertical dips. Based on aerial image and field mapping, most faults trend either toward the northwest or northeast, indicating the faults form a conjugate system similar to the joints and fractures. In addition, most field mapping identified faults trending northeast-southwest exhibited left-lateral apparent displacement.

Fault orientations throughout the Western Clipper Mountains Igneous Intrusive Suite do however exhibit a distinctive trend where the faults in unit Tvs generally strike northeast-southwest, and faults in units Tvm-b and Tvm on either side of unit Tvs are dominated by northwest-southeast trending faults. These zones dominated by faults of a particular trend are shown on Figure 2-3.

Many of the faults exhibit calcite or quartz secondary mineralization, which in places is over one foot thick. Many drainages throughout the Western Clipper Mountains Igneous Intrusive Suite have eroded along fault zones. Near the Bonanza Spring, abundant secondary weathering along fault zones was observed indicating that the faults can be strong groundwater barriers. This can be directly observed in the Tunnel Well located near and upslope from the Bonanza Spring (Figure 2-5).

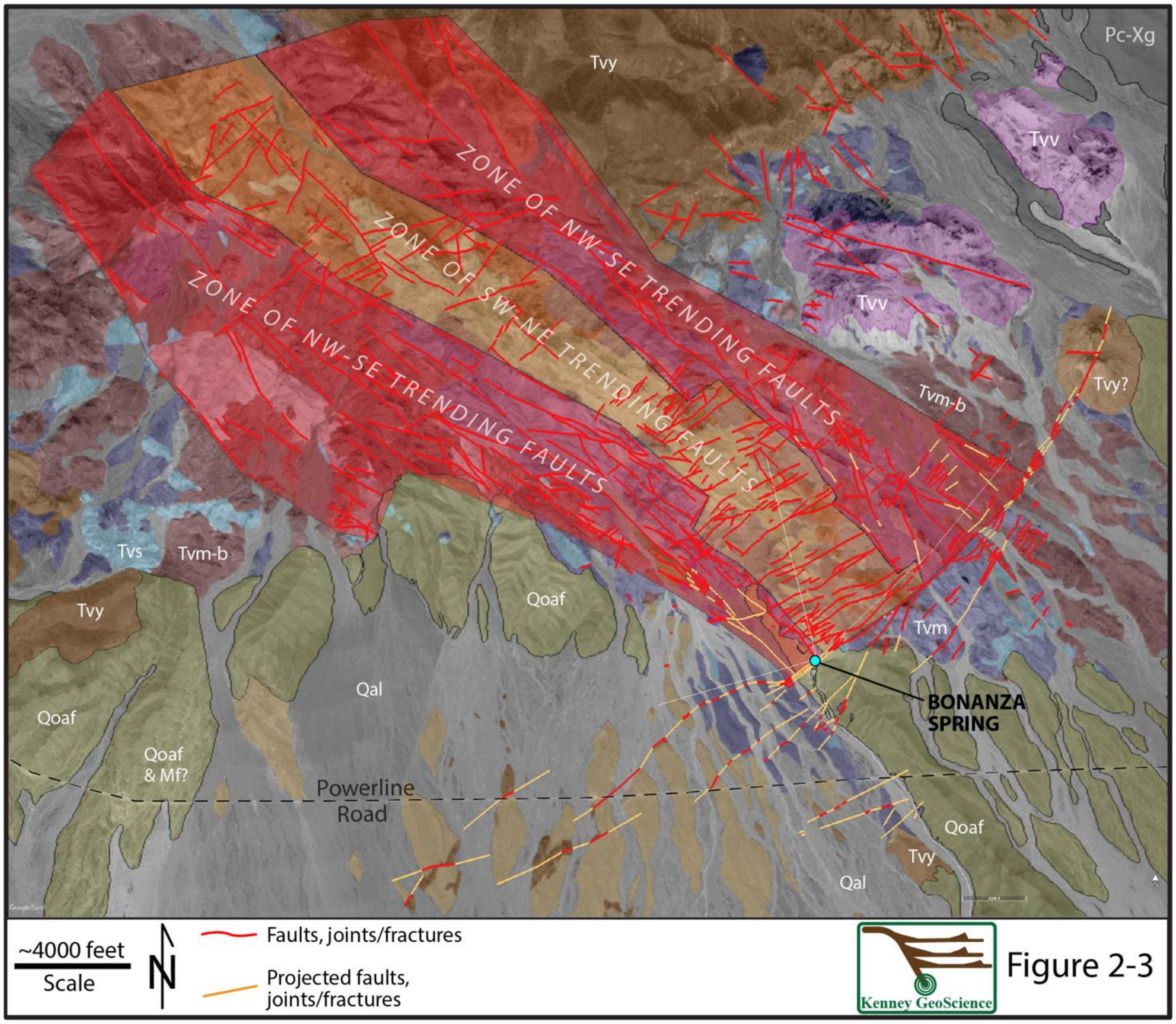


Figure 2-3 Fault zone mode map of the western Clipper Mountains

2.2.3 Igneous Dikes and Emplacement Contacts

An analysis of identifying igneous dikes and emplacement contacts was conducted primarily via evaluation of Google Earth Pro aerial imagery and in places confirmed by field mapping that demonstrated that most of the structures dip nearly vertical. The results of this analysis are shown on Figure 2-4 where thin white lines represent the igneous dike or emplacement contacts. It is evident the dike and smaller scale emplacement structures shown on Figure 2-4 essentially parallel the regional contacts between units Tvm and Tvs. Dike and emplacement structures identified clearly exhibit a higher density in unit Tvs than in units Tvm and Tvm-b, and the structures across unit Tvs and adjacent unit Tvm dominantly strike toward the northwest (Figure 2-4).

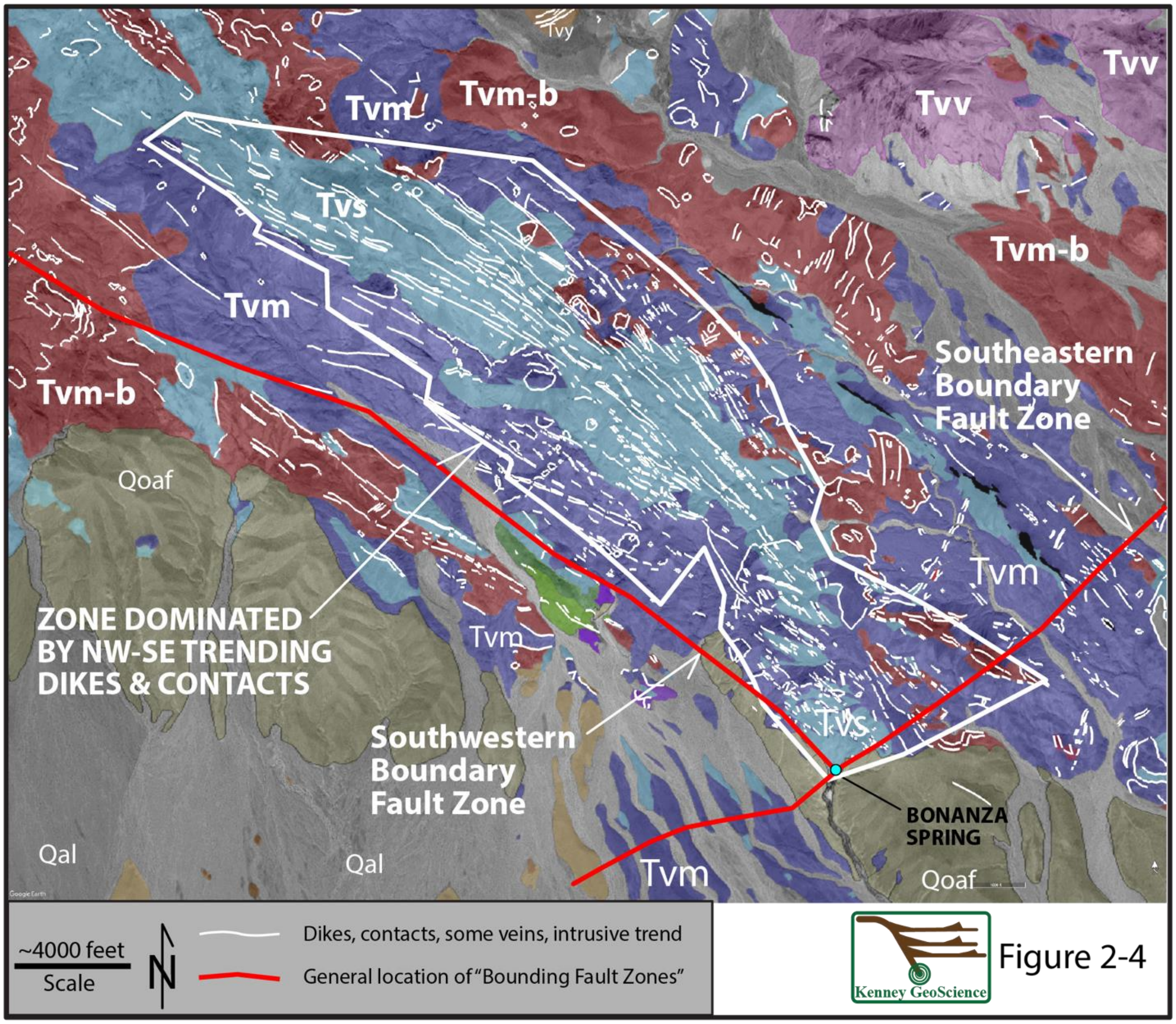


Figure 2-4 Igneous instrusive dikes and emplacement contacts of the Western Clipper Mountains

2.3 Spring-Related Geologic Features

The Bonanza Spring occurs at the base of the southwestern Clipper Mountains essentially at the contact of mountain flanking alluvium and mountain bedrock. However, the spring itself is in bedrock and its occurrence along the flank of the mountains is not related to local alluvium. The Bonanza Spring is located in a relatively small cuspate shaped "valley" exhibiting a relief of approximately 500 feet. The local surface "watershed" for the cuspate shaped valley is approximately 30-acres (Figure 2-5). Grading, involving cut and fill operations, occurred within a fairly large area within the Bonanza Spring cuspate valley (Figure 2-5). However, due to the highly fractured bedrock terrane, the watershed catchment contributing to the spring is much larger and is discussed is Section 3 below. The grading likely occurred during the early 1900's and involved the area where the current Bonanza Spring is located (Figure 2-5). It is unknown how much the grading may have affected the Bonanza Spring; however, the spring occurs in a dug out "trench" that appears to be manmade. The grading in the Bonanza Spring valley has altered precipitation runoff to the extent that flows are likely stronger than “natural” and likely carry more bedload (sediment) than pre-grading.

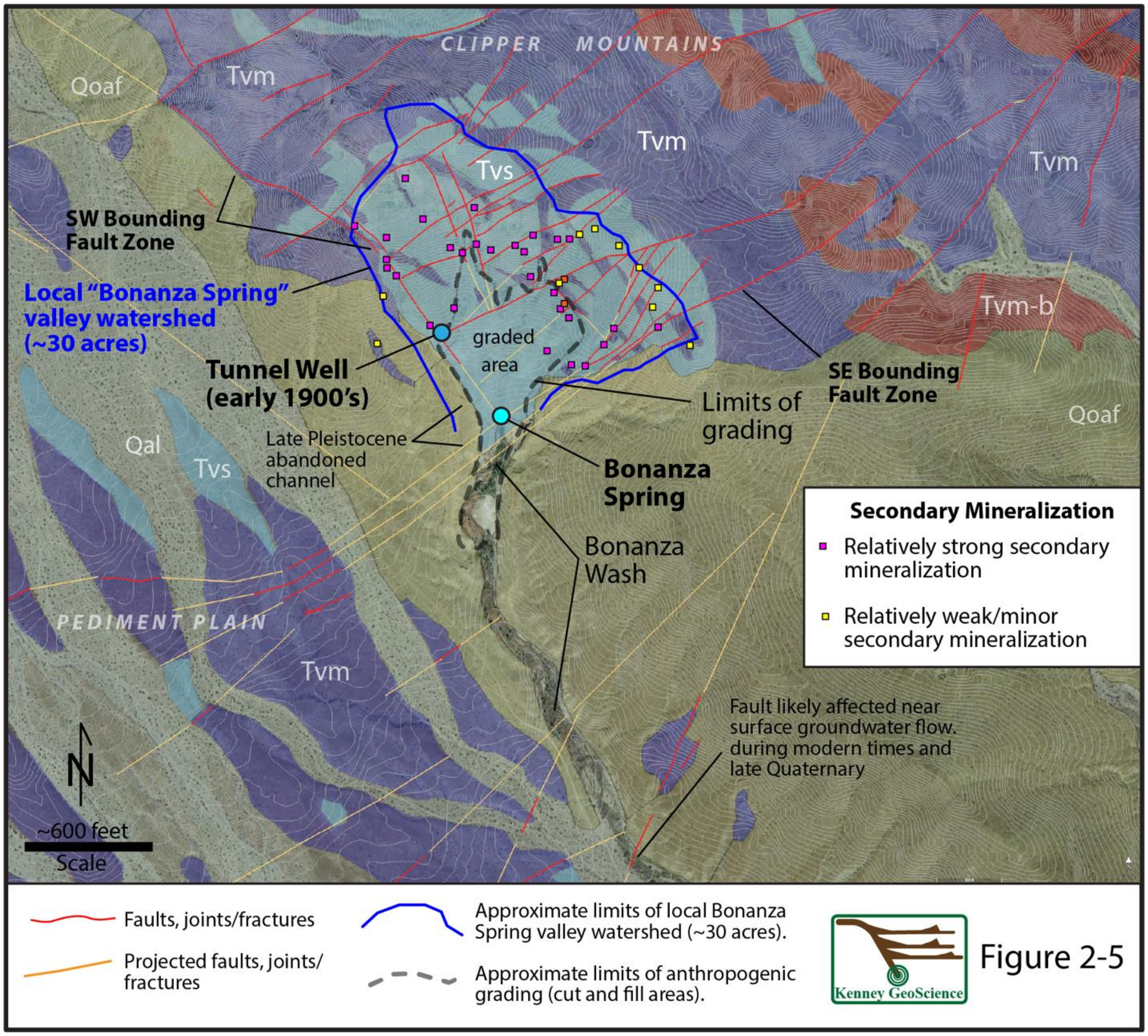


Figure 2-5 Pertinent geologic features near Bonanza Spring

Field mapping within the Bonanza Spring local cuspute valley identified areas of moderate to strong secondary mineralization and weathering that are markedly stronger than typical rocks of the Western Clipper Mountains Igneous Intrusive Suite. This was observed as chemical weathering of plagioclase phenocrysts in the igneous rocks, joints filled with iron and quartz crystallization (veins), and abundant penetrative secondary mineralization that led to abundant colorful (reds, orange, purple color) secondary minerals and abundant liesegang banding rings. It should be pointed out however that minor zones of secondary veins of quartz and iron minerals along joints occurred in many areas of the Western Clipper Mountains Igneous Metamorphic Suite and are not unique to the Bonanza Spring cuspate valley area.

Along the outer limits of the immediate Bonanza Spring cuspate valley area, the degree of secondary chemical weathering and mineralization dramatically decreased (Figure 2-5). Moderately to strongly altered rocks in the vicinity of the Bonanza Spring occur from the spring area to nearly the top of the local ridges toward the north, and slightly below the mountain ridges to the northeast (Figure 2-5). These observations suggest that fluids once flowed more strongly in the immediate area of the Bonanza Spring cuspate valley than in the surrounding rocks. In addition, these findings suggest that in the past fluids once flowed at higher elevations and that the fluids preferentially may have primarily flowed from the north.

The spring occurs at the southern limit of a 4 to 5 mile long and 1.5 mile wide region of nearly 100 percent bedrock exposures of the Western Clipper Mountains Igneous Intrusive Suite (Figure 2-2) and the spring flows from bedrock. These bedrock exposures are exposed across the entire western Clipper Mountains (Figure 2-2). In this region, the igneous member contacts (i.e., Tvm-b, Tvm and Tvs), dikes and igneous emplacement structures within the Western Clipper Mountains Igneous Intrusive Suite, all trend northwest to southeast essentially cumulating in the southwestern Clipper Mountains at the Bonanza Spring. Unit Tvs occurs along a topographic axis located in the central region of the Western Clipper Mountains Igneous Intrusive Suite, and this unit, as well as the other igneous rocks in the region are highly fractured and jointed. The Bonanza Spring is located within unit Tvs at its southern most exposure (Figure 2-4). Dikes and internal emplacement structures within unit Tvs exhibit a dominantly northwest-southeast trend, which is parallel to general unit member contacts of the Western Clipper Mountains Igneous Intrusive Suite (Figure 2-4).

Faulting in the Western Clipper Mountains Igneous Intrusive Suite exhibit modal areas where the faults generally trend northeast-southwest within unit Tvs, and northwest-southeast in the bounding units Tvm-b and Tvm (Figure 2-3). However, there is an over 3 mile long, prominent northeast-southwest trending fault zone that occurs from the Pediment Plain all the way across the southeastern limits of the entire region mapped as the Western Clipper Mountains Igneous Intrusive Suite (Figure 2-3, Figure 2-4 and Figure 2-5). This fault zone is exposed in washes located along the southeastern boundary of the cuspate shaped watershed area of the Bonanza Spring (Figure 2-5) and exhibits an over 15 to 20-foot thick sheared-gouge zone of highly jointed, sheared and fluid altered rocks. This fault zone is referred to herein as the Southeastern Bounding Fault Zone and delineates the southeastern extent of the Bonanza Spring cuspate valley (Figure 2-3, Figure 2-4 and Figure 2-5). In addition, there is a relatively prominent northwest-southeast trending fault zone along the southwestern limit of the Bonanza Spring cuspate valley referred to as the Southwest Bounding Fault Zone (Figure 2-5). The Southwest and Southeast Bounding Fault Zones intersect at the Bonanza Spring, which is the southern limit of the Bonanza Spring cuspate valley (Figure 2-5). Hence, differential erosion along these two prominent fault zones played an important role in the development of the Bonanza Spring cuspate valley in addition to the fault zones existing as groundwater barriers.

Faults within the Western Clipper Mountains Igneous Intrusive Suite are identified near the Bonanza Spring as groundwater barriers, which is observed directly in the herein named Tunnel Well located approximately 500 feet northwest of the Bonanza Spring (Figure 2-5). The Tunnel Well exhibits a ~N37W trending fault zone with a nearly vertical dip and is part of the Southwestern Bounding Fault Zone (Figure 2-5). The fault zone is within unit Tvs and consists of highly sheared rock that is a minimum of five feet thick. This fault zone projects to the southeast to intersect with the Bonanza Spring itself which is also the intersection of the Southeastern Bounding Fault Zone (Figure 2-5). The Tunnel Well fault zone is part of a zone exhibiting numerous northwest-southeast trending faults occurring along the southwestern region of the Western Clipper Mountains Igneous Intrusive Suite (Figure 2-3). Hence, in terms of fault structures, the Bonanza Spring occurs at the intersection of two relatively prominent fault zones both of which exhibit evidence of being groundwater barriers. In addition, the area of increased secondary mineralization and chemical weathering observed in the Bonanza Spring cuspate valley area is bounded by the Southeastern and Southwestern Bounding Fault Zones. As discussed, these two prominent fault zones delineate the southwestern and southeastern boundary of the Bonanza Spring cuspate valley, which likely resulted from weakening of the rocks north of the fault zones due to groundwater weathering and differential erosion along the fault zones themselves (Figure 2-5).

It is interesting that the Tunnel Well was likely excavated not for minerals, but instead to obtain groundwater. Old metal piping is observed to have been installed into the tunnel where a mound of earth at the tunnel's entrance allowed for ponding water to occur inside the tunnel. It can be presently observed in the tunnel that the fault zone is a groundwater barrier —rocks northeast of the fault zone are moist, and rocks with the fault gouge zone are dry. Groundwater may have historically been higher here (a spring?) than in other locations in the Bonanza Spring cuspate valley due to the intersection of the Southwestern Boundary Fault Zone and a northeast-southwest trending smaller scale fault extending across the valley to the northeast (Figure 2-5). These data suggest that the Tunnel Well "spring" exhibits a small-scale version in terms of fault structure as that indicated for the Bonanza Spring – i.e. groundwater mounded behind the intersection of two fault zones at high angles to one another.

An ancient abandoned channel of likely late Pleistocene age was identified less than 200 feet west of the Bonanza Spring (Figure 2-5). The abandoned channel is approximately 10 to 15 feet above the current Bonanza Spring Wash elevation and once flowed essentially due south. The significance of the abandoned wash with the Bonanza Spring is that abundant travertine deposits occur in the sediments at the base of the wash and adjacent bar deposits. The carbonate travertine deposits are over eight feet thick and due to their elevation above the current Bonanza Spring, suggest that during the Pleistocene, groundwater levels in the area of the Bonanza cuspate valley area were over 10 to 15 feet higher at minimum. This observation is consistent with the pronounced secondary weathering and mineralization of rocks at higher elevations within the Bonanza Spring cuspate valley (Figure 2-5).

2.4 Subsurface Structure – Cross Sections

To assist in the groundwater analysis conducted by the co-author, two local cross sections were constructed by Kenney GeoScience that intersect at the Bonanza Spring. These include Cross Section A-A' (Figure 2-6a and Figure 2-6b), and Cross Section B-B' (Figure 2-7a and Figure 2-7b).

Cross Section A-A' is approximately 2.64 miles long and trends northeast-southwest across the emplacement grain of the Western Clipper Mountains Igneous Intrusive Suite (Figure 2-6a and Figure 2-6b). This cross section extends across the exposures of the Zabriskie Quartzite associated with the Clipper Mines in the northeast in the Clipper Mountains, and extends toward the southwest onto the Pediment Plain. Units Tvy and Mf are shown in the southwestern limit of Cross Section A-A' and dipping toward the south. Both of these units were deposited on the earth's surface and not emplaced from depths below as is the case of the nearly vertical structures shown in the Western Clipper Mountains Igneous Intrusive Suite, faults and dikes.

Cross Section A-A’ exhibits the vertical emplacement structure of the Western Clipper Mountains Igneous Intrusive Suite as well as the nearly vertical dip of most of the faults and dikes. Cross Section A-A’ shows a subtle synform in the Western Clipper Mountains Igneous Intrusive Suite demonstrated by variations of dips of intrusive dikes. This synform suggests that the local rocks may have been folded. It is interesting that the synform occurs along the central region of unit Tvs, which itself is the central region of the Western Clipper Mountains Igneous Intrusive Suite. It is evident from Figure 2-2, that the Western Clipper Mountains Igneous Intrusive Suite exhibits a mirror pattern where the outer reaches of this area are dominated by unit Tvm-b, toward the center a region dominated by Tvm, and the center region itself dominated by unit Tvs.

Cross Section B-B’ is approximately seven miles long and extends from within the Western Clipper Mountains Igneous Intrusive Suite in the north, across the Bonanza Spring cuspate valley, the Bonanza Spring, down Bonanza Wash, across Route 66, across Fenner Wash, and the railroad line near Dandy (Figure 2-7a and Figure 2-7b). The section shows the vertical structures associated with the Western Clipper Mountains Igneous Intrusive Suite occurring from the Western Clipper Mountains, under the Bonanza Spring, and continuing further south of the spring along the northern portion of the Pediment Plain, which along this section coincides with Bonanza Wash. The Bonanza Wash occurs within a bedrock swale in which bedrock associated with the Western Clipper Mountains Igneous Intrusive Suite are exposed at higher elevations immediately to the west and east of the wash, and in places, exposed within the wash itself. Hence, alluvial deposits along the Bonanza Wash from the Bonanza Spring to the southern limits of the Pediment Plain are generally less than a few feet.

Units Tvy and Mf are exposed along an approximately 130-foot tall ridge located immediately west of the Bonanza Wash (Figure 2-7a and Figure 2-7b). This region generally represents the southern limits of the erosional Pediment Plain; however the ridge itself is an erosion remnant of once larger hills across the area. Units Tvy and Mf were deposited on the surface of the earth presumably in approximately horizontal layers. Subsequent to their deposition however, these units tilted toward the south; locally along Cross Section B-B’, they tilted approximately 35 degrees. The total thickness of interbedded units Tvy and Mf is unknown, and is simply shown as a very thick unit underlying older alluvium toward the south. Some constraints of the depth of older alluvium in the Fenner Valley region is provided by wells.

Figure 2-6a Geologic map of southwestern Clipper Mountains for Cross Section A-A'

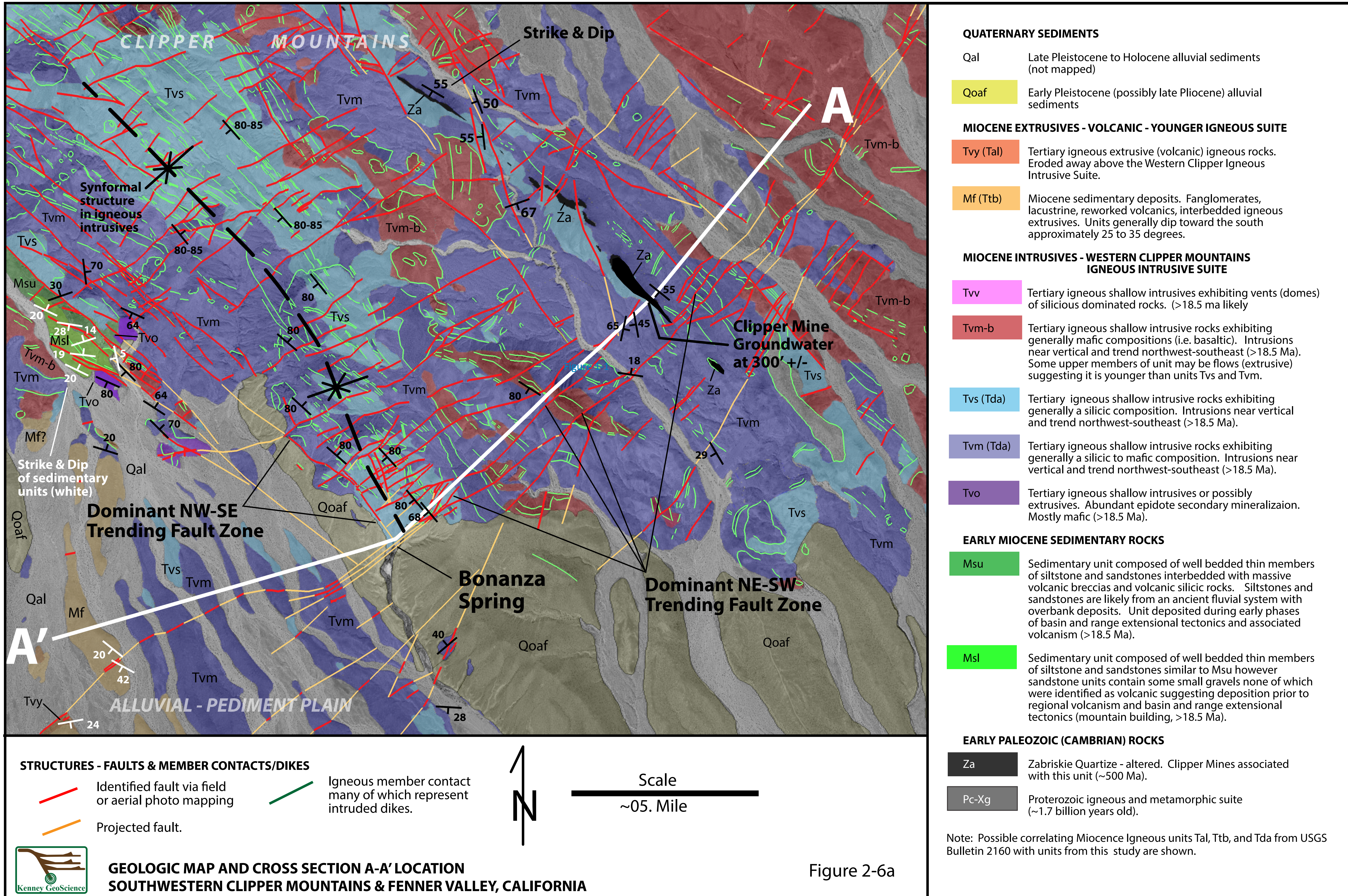
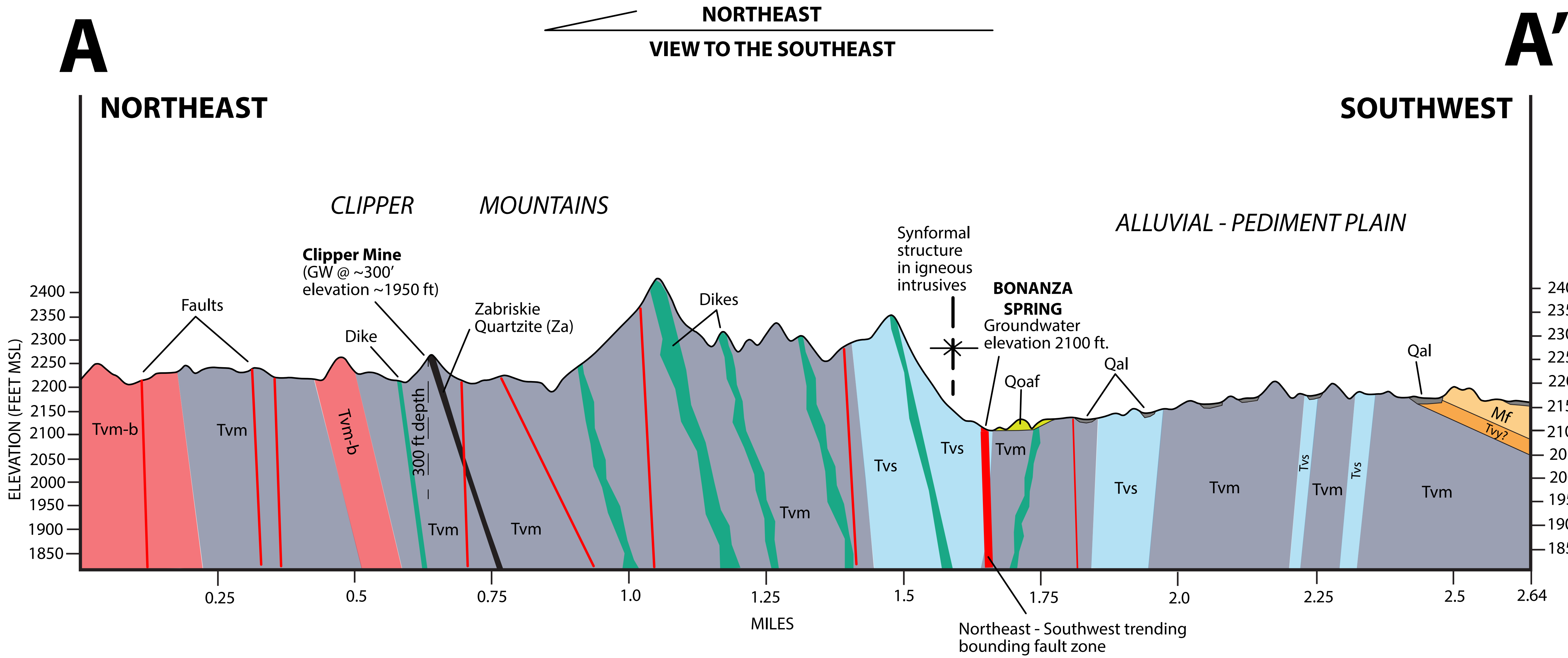


Figure 2-6b Cross Section A-A'

CROSS SECTION TRENDING NE TO SW NORTH OF BOUNDING FAULT ACROSS THE BONANZA SPRING, SOUTHEASTERN CLIPPER MOUNTAINS

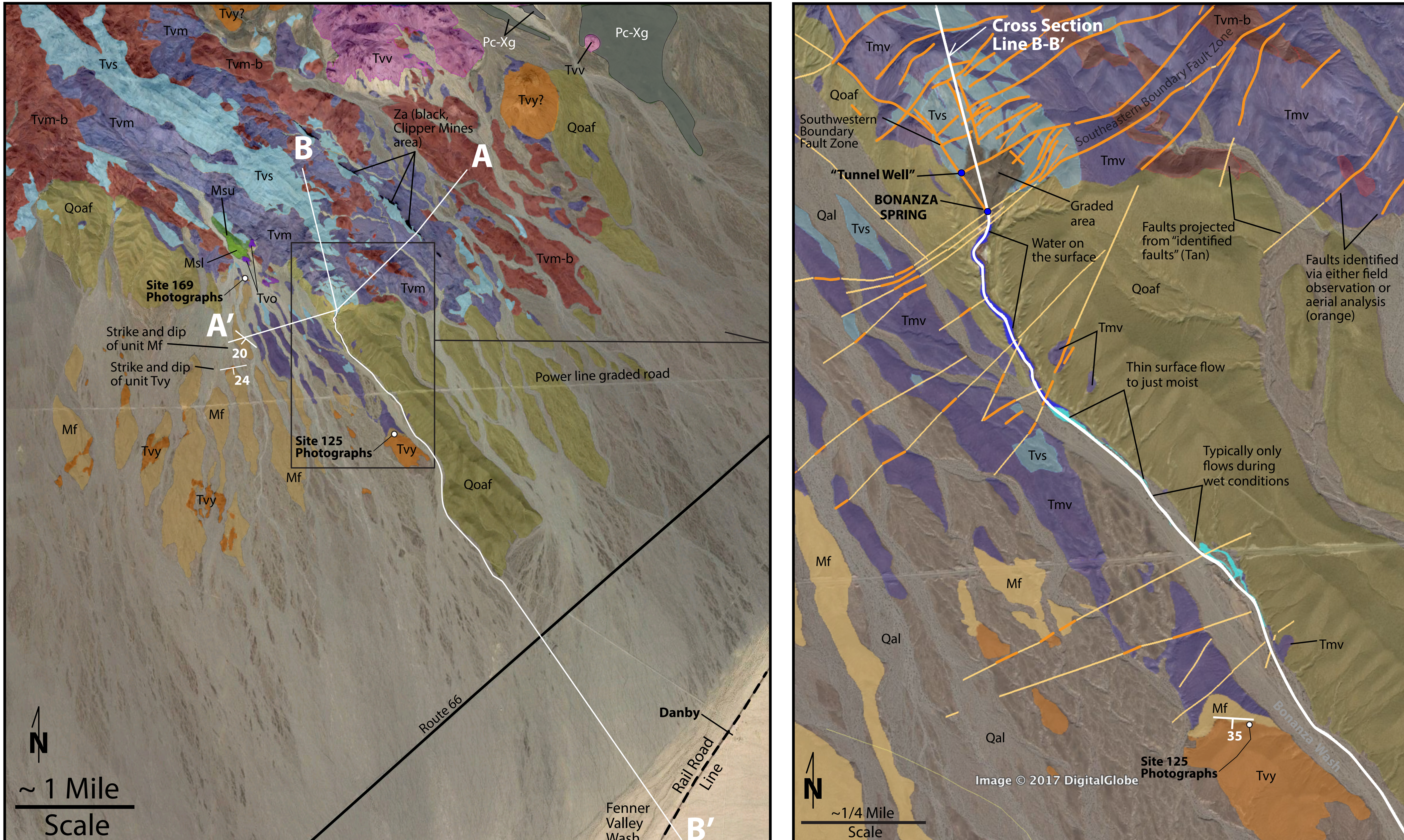


Kenney GeoScience

GEOLOGIC CROSS SECTION A-A'
SOUTHWESTERN CLIPPER MOUNTAINS & FENNER VALLEY, CALIFORNIA

Figure 2-6b

Figure 2-7a Geologic map of southwestern Clipper Mountains for Cross Section B-B'



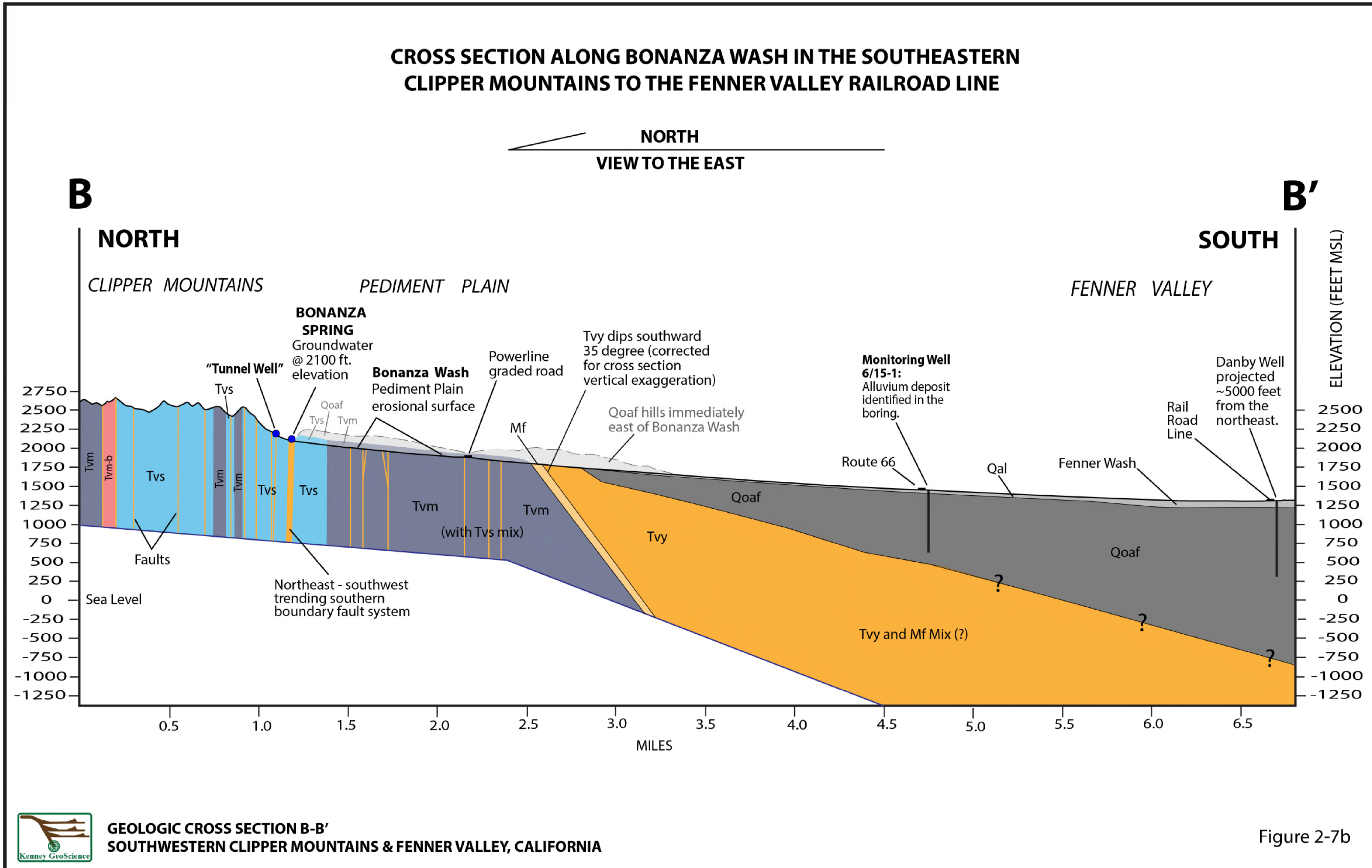
GEOLOGIC MAP AND CROSS SECTIONS A-A' & B-B' LOCATIONS
SOUTHWESTERN CLIPPER MOUNTAINS & FENNER VALLEY, CALIFORNIA

Kenney GeoScience

NOTE: See Figure 2-1 for Geologic unit descriptions.

Figure 2-7a

Figure 2-7b Cross Section B-B'



3.0 Hydrogeology of Bonanza Spring Area

This section describes the hydrogeology of the Bonanza Spring area, including hydrogeologic units, groundwater recharge and groundwater occurrence and flow.

3.1 Hydrogeologic Units

There are three principal hydrogeologic units in the Bonanza Spring area, which are identified in Figure 2-1. The three units include a sedimentary unit and two crystalline rock units as follows: 1) the combined younger and older alluvium (map symbols Qal and Qoaf), referred to in Section 3 simply as the Alluvial Aquifer Unit; 2) Extrusive Volcanic Unit (combine map units Tvy and Mf) and; 3) Intrusives Unit (combination of map symbols Tvm-b, Tvs, and Tvm). The characteristics of these units are described in detail in Section 2.

The Intrusives and Extrusive Volcanic Units are characterized by secondary porosity and permeability resulting from faulting and fracturing, as compared to primary porosity and permeability exhibited by the Alluvial Aquifer Unit, which is associated with intergranular pore spaces. The Alluvial Aquifer typical exhibits similar hydrogeologic properties over its thickness and variations are due primarily to variations in texture, (e.g., sand and gravel generally are more transmissive than silt and clay). Hydrogeologic properties of the Intrusives and Extrusive Volcanics Unit, such as specific yield and transmissivity, are a function of fracture density, fracture aperture (i.e., width and roughness), precipitation of minerals within fractures, and depth below land surface. In general, porosity and transmissivity of crystalline rocks decrease with depth as fracture density decreases and fracture apertures are closed with the weight of the rock above. Numerous investigators have shown that groundwater production capacities of wells decreases significantly with depth (e.g., Freeze, 1979, Fetter, 1980, and Krasny and Sharp, 2007). Krasny and Sharp (2007) state that, "The upper and middle zones (influenced by weathering and fracturing) can form a regionally extended "near surface aquifer" that is generally conformable to the land surface with a thickness of tens to more than a hundred meters with permeability generally decreasing with depth. This aquifer usually offers the best groundwater abstraction possibilities. However, the thickness and character of this complex and heterogenous aquifer changes spatially in relation to tectonic deformation (faulting and fracturing), lithologic facies, and weathering." Most of these studies suggest that porosity and transmissivity is dramatically reduced below a couple hundred meters (600 to 700 feet).

3.1.1 Alluvial Aquifer Unit

The Alluvial Aquifer Unit is the upper-most hydrogeologic unit, thins near valley margins, and thickens to over 2,000 feet in the Fenner Valley. It is largely unsaturated except in the Fenner Valley, where it is the principal aquifer. This unit is very transmissive and has a high storage capacity as described in CH2M HILL (2010) and Geoscience Support Services Inc. (GSSI, 2011). Hydraulic conductivity values range from a few feet per day to tens of feet per day. Specific storage values average around 15 percent. This unit holds millions of acre feet of groundwater in storage (CH2M HILL, 2010).

3.1.2 Extrusive Volcanic Unit

The Extrusive Volcanic Unit occurs as aerially extensive outcrops on the north-northwestern side of Clipper Mountains and as smaller outcrops around the western and southwestern Clipper Mountains. As described above, these units are the youngest units associated with Miocene extensional tectonism and the last deposited in the western Clipper Mountains area (study area). As shown in cross section B-B'

(Figure 2-7b), these units likely dip beneath the alluvium of the Fenner Valley. However, their total stratigraphic thickness remains unknown.

There are no aquifer tests in the local Extrusive Volcanic Unit. Literature values of hydraulic conductivity values suggest a wide range of values depending upon the specific type of volcanic unit. Transmissivity values for permeable basalt may range from 10 to 1000s of ft^2/day (Krasny and Sharp, 2007). Transmissivity values for slightly-to-highly fractured volcanic rocks may range from 10s to 100s ft^2/day. Storage capacity of this unit may range from less than five to as much as 50 percent. Figures 3-1 and 3-2 show photographs of exposures of the Extrusive Volcanic Unit downstream of the Bonanza Spring area. These photos show that this unit may exhibit a full range of transmissivity and storage properties. In particular, the photos in the top row shown in Figure 3-2 show large cavities and cavernous volcanics similar to karstic limestone. These subunits would be capable of transmitting large quantities of water. Such volcanic extrusive units are typical targets in groundwater resources programs for developing high capacity production wells.

Figure 3-1 Photographs of Extrusive Volcanic Unit at Site 169 (see Figure 2-7a for location)

3.1.3 Intrusives Unit

The Intrusives Unit is made up of fractured Tertiary igneous intrusive rocks, spanning silicic to mafic composition as described in Section 2.1.5. The more silicic units occur immediately north of Bonanza Spring and trend northwest to southeast, contain extensive vertical dikes, and are highly fractured. This more silicic unit (Tvs) is clearly visible in Google Earth imagery as lighter color rocks and sharp ridges extending northwest to southeast (see Figure 2-2) and is bounded by silicic to mafic intrusive igneous rocks. The outer-most mafic units are shallow intrusive rocks, with some upper members that may be extrusive flows. All units contain vertical dikes, but the highest density of dikes are in the more silicic units (see Figure 2-4).

Figure 3-2 Photographs of Extrusive Volcanic Unit at Site 125 (see Figure 2-7a for location)

As the Intrusives Unit is highly fractured, its transmissivity values likely range between 10 to as high as several 100 ft^2/day (Krasny and Sharp, 2007). The transmissivity values of the more silic Tvs subunit may tend toward the upper end on average given the highly fractured nature of this unit. Storage capacity of fractured igneous rocks range from 0 to 10 percent and likely average around five percent for the Intrusives Unit (CH2M HILL, 2010), but decrease with depth. Krasny and Sharp (2007) and references therein, report that fracture density and aperture decrease significantly with depth. Typically, these fracture zones are around 300 feet thick, but may extend to 600 feet or so below ground surface in some geologic settings. Groundwater flow below about 600 feet in the Intrusives Unit is expected to decrease significantly with increasing depth, especially for the more mafic subunits, which are less fractured than the more silicic subunits.

3.2 Groundwater Recharge and Storage

This section describes groundwater recharge and storage in the catchment area of the Bonanza Spring. The spring is sustained as a perennial spring as a result of long-term recharge and groundwater storage in the spring's catchment area. In some years, there is little recharge and the volume of groundwater storage is reduced; in other years, there is substantial recharge and storage is replenished, sustaining the spring. As long as the climate is characterized by sufficiently wet conditions, groundwater storage can be maintained to sustain the spring through dry cycles and long-term droughts.

3.2.1 Groundwater Recharge

CH2M Hill (2010) found that groundwater recharge occurs primarily in the mountains of the Fenner and Cadiz watersheds. The distributed parameter soil-moisture budget model known as INFIL3.0 (USGS, 2008) was used by CH2M HILL to estimate recharge to the Fenner-Cadiz-Bristol groundwater basins. INFIL3.0 model results show that precipitation over the Clipper Mountains infiltrates the fractured intrusive and extrusive rocks below the plant root zones and becomes deep groundwater recharge. Long-term average recharge on Clipper Mountains is estimated to be 2,400 AFY using the INFIL3.0 model (CH2M HILL, 2011).

The likely catchment area for groundwater recharge upgradient of the Bonanza Springs is shown in Figure 3-3 and Figure 3-4. The basis for identifying this catchment area is described as follows:

- The convergence of the two bounding faults, one trending northwest to southeast and the other trending northeast to southwest (Figure 3-4),
- The western extent of the eastern zone of northwest-southeast striking faults, as described in Section 2.3 and Figure 2-3 and shown in Figure 3-4,
- The upstream extent of the watershed of surface drainages that drain the east-southeast area of Clipper Mountains in the zone defined by the first two items.

The catchment is approximately 2,350 acres. The long-term recharge of this catchment area is estimated from the INFIL3.0 model results presented by CH2M HILL (2010). As the average long-term unit recharge rate is estimated to be approximately 0.0794 ft/yr, over the catchment area the quantity of recharge is about 190 AFY, about eight percent of the total recharge in the Clipper Mountains. Recharge varies year to year depending on precipitation.

3.2.2 Groundwater Storage Above Bonanza Spring

Groundwater in storage above the elevation of Bonanza Springs (2,100 feet) is important as this is the volume of water that sustains the spring during prolonged dry periods, including droughts. Groundwater levels likely increase to the northwest within the catchment area as a result of ongoing groundwater recharge, which is also supported by perennial flow of the spring (i.e., a hydraulic gradient is required to provide ongoing flow to the spring). This storage volume is expected to fluctuate in response to long-term variations in recharge.

As described above, the likely depth of fractured rock is expected to be in the range of 600 to 700 feet below ground surface and below that depth, groundwater flow is anticipated to be a *de minimis* quantity. As described below, groundwater was detected at 300 to 500 feet below ground surface approximately one mile to the east of the Bonanza Spring. Based on these depths, saturated groundwater may range from as much as 200 to 400 feet in thickness in the Intrusives Unit, upgradient of the spring. However, the saturated thickness is expected to increase downgradient toward the bounding fault as recharge accumulates and flows downgradient. In addition, there may be deadzones as a result of an undulating surface underlying the fracture zone of the Intrusive Unit. However, the storage of groundwater upgradient of the spring may be conservatively estimated using a value of, approximately 100 feet and a 0.03 specific yield over the thickness of the saturated unit. The volume (V_{gs}) of groundwater in storage above the Bonanza Spring is 7,050 AF.

$$V_{gs} = 2350 \text{ acres} * 100 \text{ ft} * 0.03 = 7{,}050 \text{ AF} \qquad (1)$$

This volume of water, even if cut by 50 percent, provides a substantial buffer against dry-year and drought conditions, when recharge is absent or significantly reduced from average.

Figure 3-3 Bonanza Spring Recharge Area Catchment and INFIL3.0 Average Annual Infiltration for 1958 through 2007 - Fenner Watershed

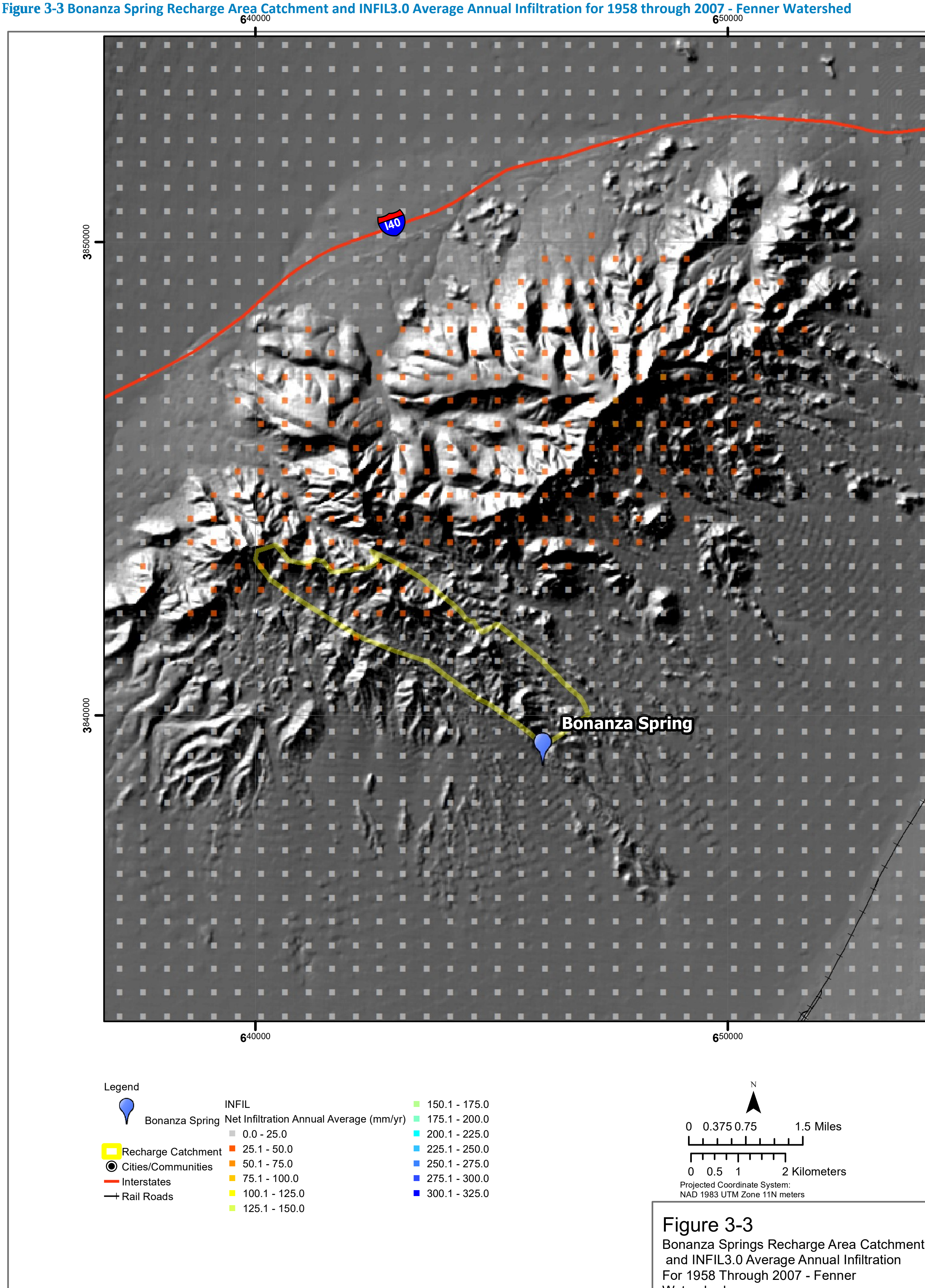


Figure 3-3
Bonanza Springs Recharge Area Catchment and INFIL3.0 Average Annual Infiltration For 1958 Through 2007 - Fenner Watershed

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3.3 Groundwater Occurrence and Flow

As indicated above, groundwater in the Clipper Mountains occurs in hydrogeologic units, comprised of fractured igneous intrusive and igneous extrusive rocks, and alluvium as described in Section 3.1. As described in Section 3.2, groundwater flows in response to a hydraulic gradient created from recharge of groundwater at higher elevations and discharge of groundwater at lower elevations, including at Bonanza Springs.

There are an additional two observations of groundwater levels that suggest groundwater flow is effectively compartmentalized by geologic conditions in parts of the Clipper Mountains. These two observations are from the Clipper Mountains and Tom Reed mines, located approximately 1 and 1.2 miles, respectively, to the northeast of Bonanza Spring as shown in Figure 3-4. The depths to groundwater in the Tom Reed mine and Clipper Mine are reported to be 500 and 300 feet respectively,

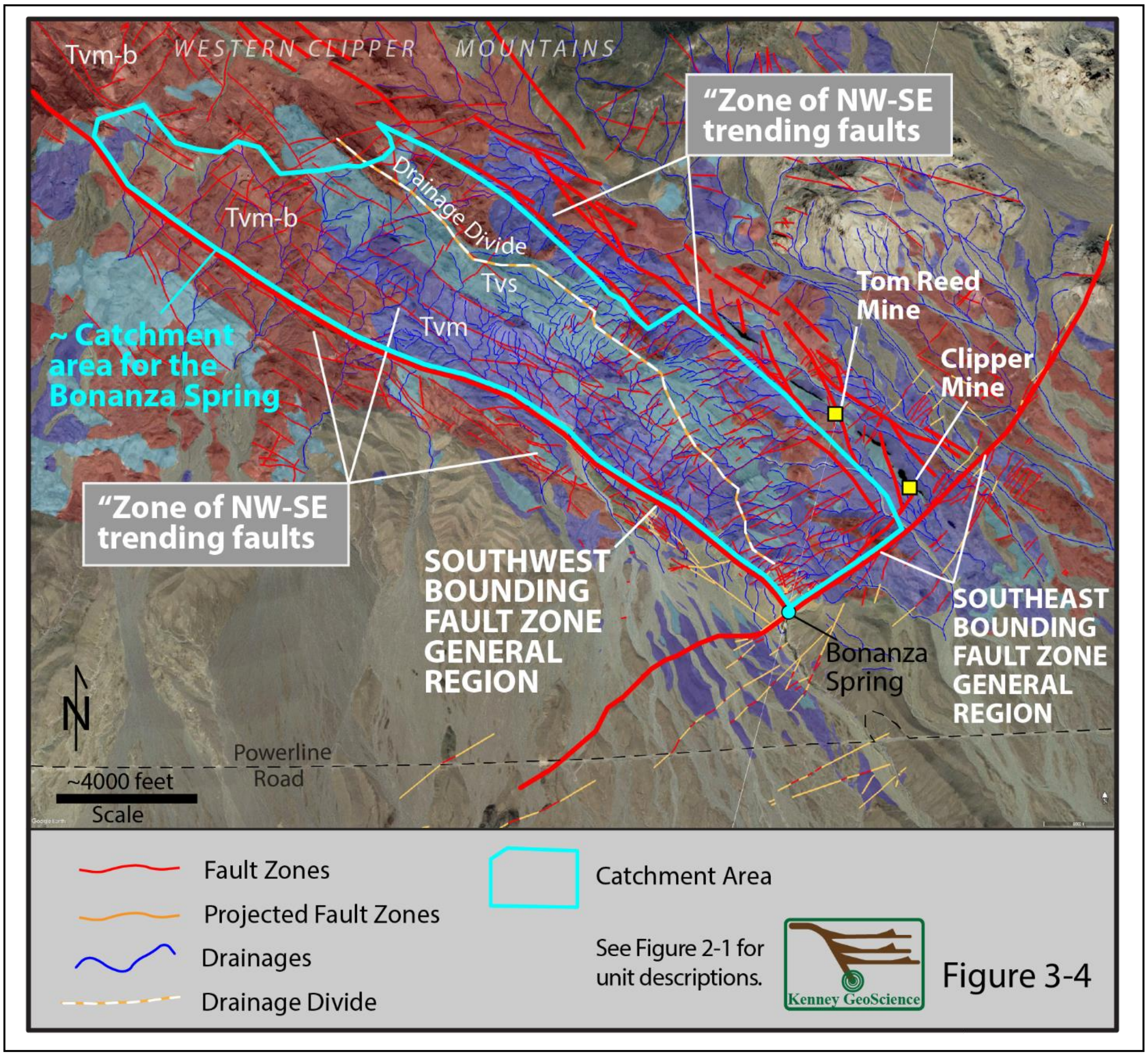


Figure 3-4 Bonanza Spring Catchment area and pertinent Geologic features

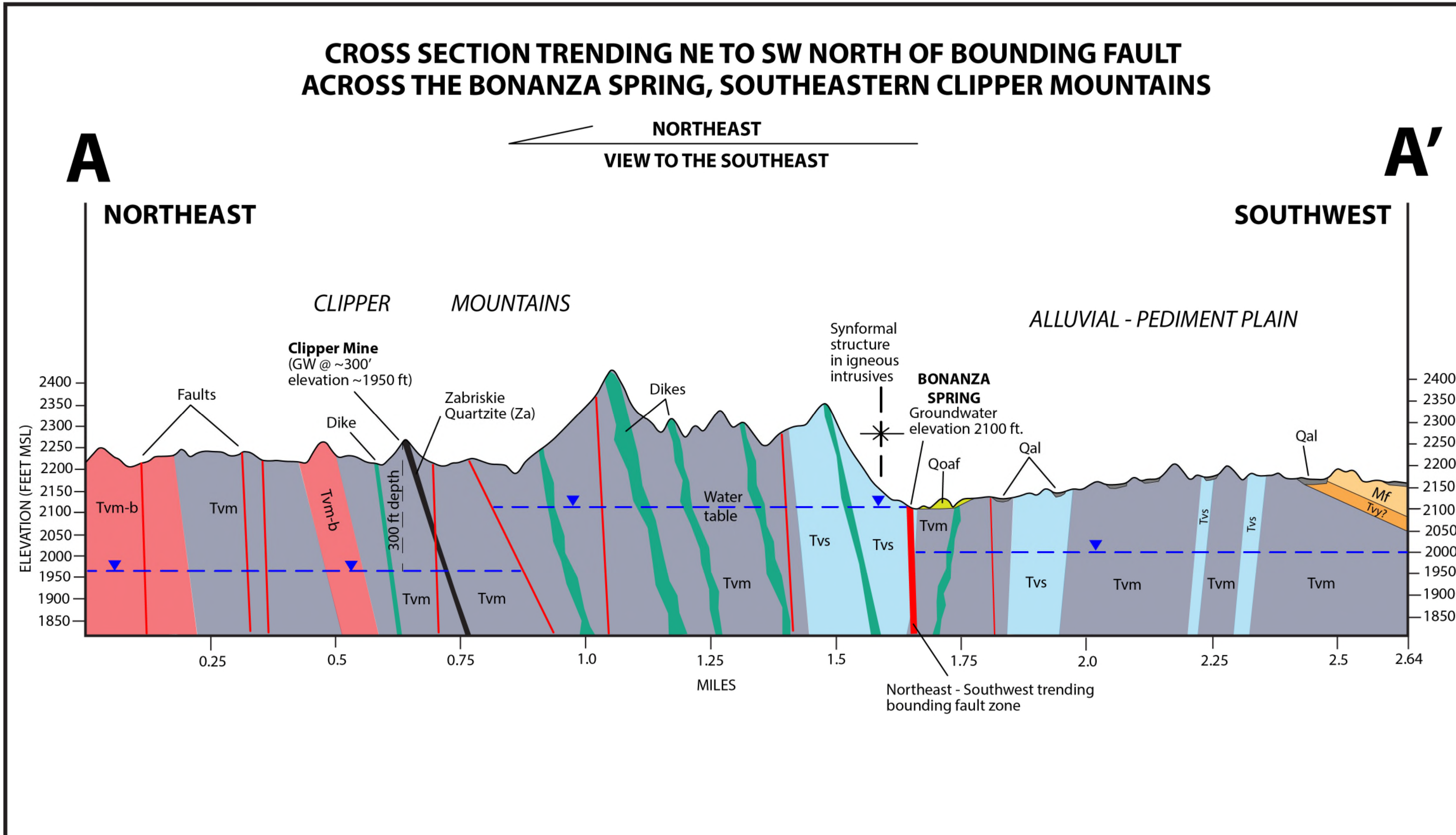
around 1917 (G. L. Shumway, et.al., 1980). The authors of this report field located these mines and determined their surface elevations, which puts the groundwater elevations at these mines at approximately 1,950 feet elevation. Groundwater elevations at the mines are over 150 lower than the level of groundwater discharge of Bonanza Spring based on these groundwater levels. It is doubtful that groundwater flows from the Bonanza Spring toward these mines. Instead, it is likely that the zone of northwest-to-southeast striking faults act as barriers to groundwater flow (see description of this zone in Section 2.2.2 and Figure 2-3). Groundwater flow may move parallel to these faults, as brecciated zones may provide for conduits along the faults, but impede flow across them.

Cross section A-A’ (Figure 3-5) shows likely groundwater conditions between Bonanza Springs and the mines to the east. Minor faults across the catchment area of Bonanza Springs may result in complex flow patterns of groundwater from the upper reaches of the catchment, but not serve as complete barriers. Groundwater likely moves along brecciated zones parallel to minor faults and dikes.

Major faults, such as the southern bounding fault at the Bonanza Spring, identified above, likely serve as barriers to groundwater flow, resulting in mounding behind these barriers. Cross section B-B’ (Figure 3-6) shows the likely pattern of groundwater flow from the Bonanza Spring downgradient to the Alluvial Aquifer in Fenner Valley. Groundwater levels in the Alluvial Aquifer are at 1,100 feet elevation about three miles downgradient of the Bonanza Spring.

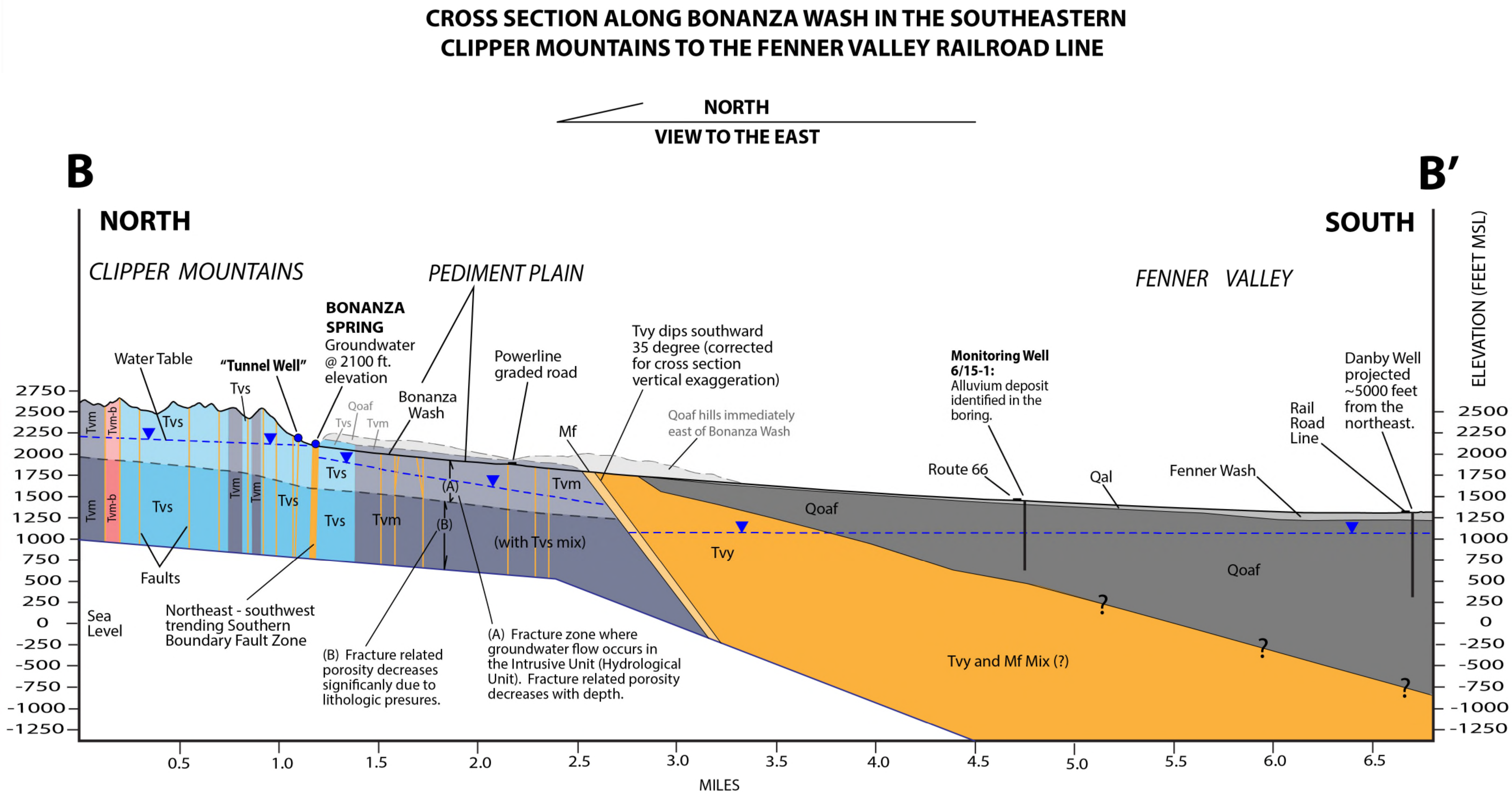
Groundwater levels across the bounding fault are likely significantly offset due to the low permeability of the fault zone, which impounds groundwater. On the downgradient side of the fault, groundwater flow is reduced relative to groundwater flow above the fault as the discharging groundwater flow is consumed by the riparian vegetation at the spring. Other faults located downgradient likely result in some mounding of groundwater levels behind them as well; however, there are no observed perennial springs downgradient of the Bonanza Spring.

Groundwater moves through fractured zones in the Intrusives Unit toward the Extrusive Unit and Alluvial Unit in Fenner Valley. This fractured zone is likely limited to the upper few hundred feet as fracture apertures typically close with depth and the transmissivity declines significantly as described above. As shown in Figure 3-6, groundwater flow occurs in the Intrusives Unit, the base of which is above the water table of the Extrusive Volcanic Unit/Alluvial Aquifer. Therefore, the flow in the Intrusives Unit is effectively hydraulically separated from the flow in the Extrusive Volcanic Unit/Alluvial Aquifer. Therefore, changes in groundwater levels in the Extrusive Volcanic Unit/Alluvial Aquifer will not affect groundwater conditions upgradient in the Intrusives Unit. These findings indicate that changes in groundwater levels in the Alluvial Aquifer from pumping will not affect discharge at Bonanza Spring.



CROSS SECTION A-A' WITH GROUNDWATER INTERPRETATION
SOUTHWESTERN CLIPPER MOUNTAINS & FENNER VALLEY, CALIFORNIA

Figure 3-5



CROSS SECTION B-B' WITH GROUNDWATER INTERPRETATION
SOUTHWESTERN CLIPPER MOUNTAINS & FENNER VALLEY, CALIFORNIA

Kenney GeoScience

Figure 3-6

4.0 Potential Impacts of the Cadiz Water Project on Bonanza Spring

The hydrogeology of the Bonanza Spring area creates robust conditions for long-term sustainability of the spring. The following conditions support the sustainability of the spring:

- The catchment area is fault bounded, which creates a barrier to groundwater outflow from the catchment. The groundwater outflow must be less than the long-term average recharge minus the spring discharge (which is consumed by plant evapotranspiration and infiltration) as shown by the following Equation 2, otherwise, groundwater levels would drop below the elevation of the spring and the spring would dry up:

$$O_g < R - D_s \qquad \text{(Equation 2)}$$

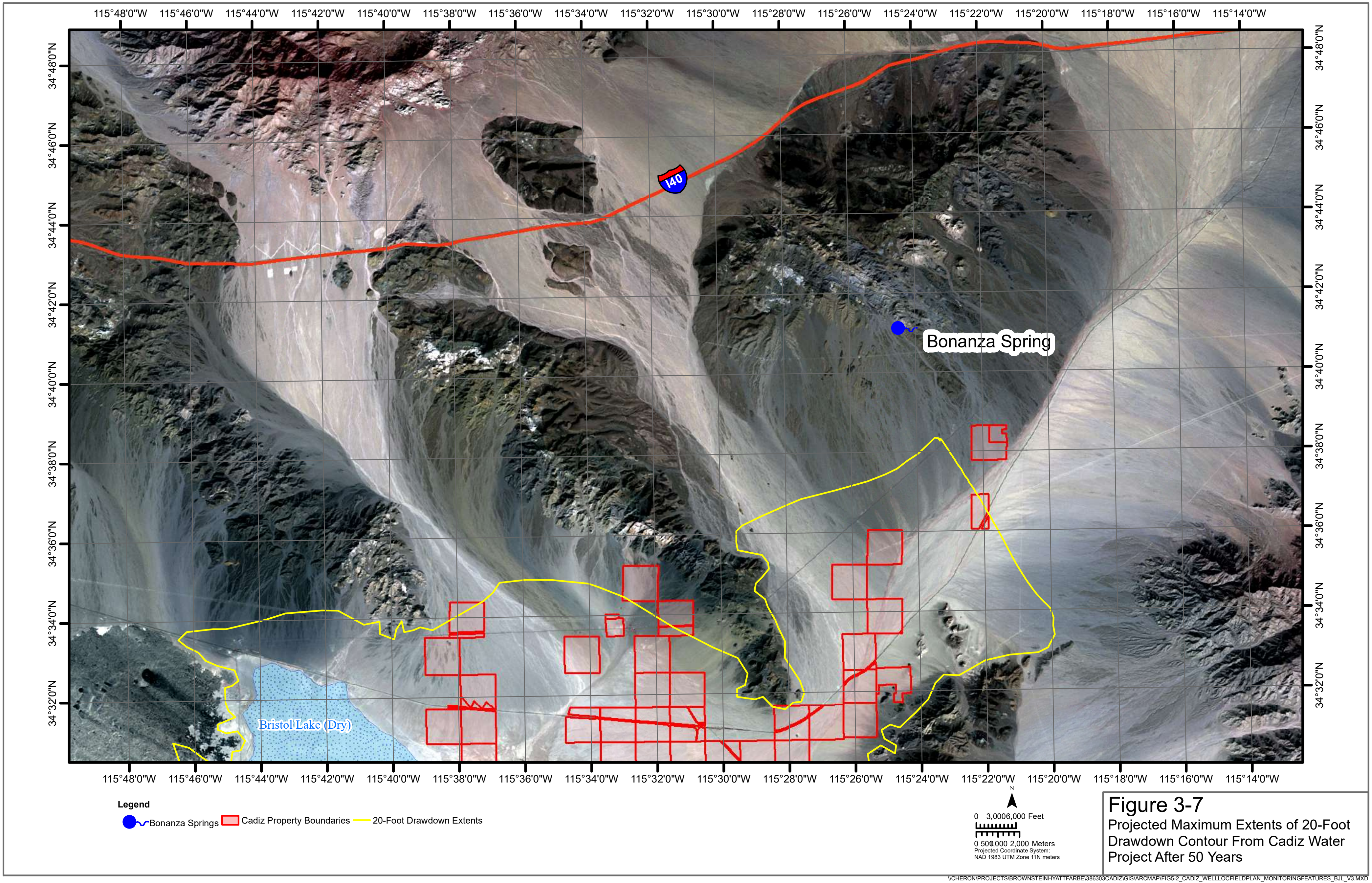
  Where O_g is groundwater outflow across the fault-bounded catchment, R is recharge over the catchment and D_s is spring discharge (consumed by evapotranspiration and infiltration downgradient of the fault).
- Long-term average groundwater recharge is greater than long-term average O_g and D_s, which maintains groundwater storage in the fault-bounded catchment area of the spring.
- The likely volume of groundwater in storage, above the elevation of the spring (2,100 feet), is on the order of thousands of AF, and as estimated above, could be as much as 7,050 AF. This storage volume is equal to over 37 years of long-term average recharge. Even if the storage volume was half this amount, it would represent over 18 years of long-term average recharge. However, in wet periods the gradient is expected to increase, resulting in increased flow to the spring and in dry periods, as storage is reduced, the gradient is decreased and spring flow would also decrease.
- The volume of groundwater in storage is sufficient to maintain the spring through substantial periods, potentially droughts lasting several decades, but with reduced discharge.

Therefore, we conclude that the existence of the spring is dependent on long-term average recharge to maintain groundwater levels and storage above the elevation of the spring, where it discharges across the convergent bounding faults.

The Water Project wellfield will operate in and southwest of the Fenner Gap, approximately 11 miles from the Bonanza Spring. The wellfield will extract 50,000 AFY on average, ranging from 25,000 AFY to 75,000 AFY in any given year. Groundwater flow simulations using three-dimensional numerical groundwater flow models of the operation of the Water Project are described in detail in the FEIR (2012). In an abundance of conservatism, groundwater flow model simulations included a range of recharge rate scenarios to examine potential groundwater-level declines. Recharge rates were varied from 5,000 AFY to 32,000 AFY. Figure 3-7 shows the maximum extents of the 20-foot drawdown contour as combined from all recharge scenarios. Beyond this contour line, drawdown was projected to be less than 20 feet under all recharge rate scenarios simulated using the groundwater flow models.

The drawdown effects will not extend to the spring area due to a hydraulic disconnect between the Intrusives Unit and the Extrusive Volcanic Unit/Alluvial Aquifer unit as described above, as well as the occurrence of faults between the spring area and the Fenner Valley. Consequently, the drawdown effects from the Water Project will be limited to the Alluvial Aquifer. CH2M HILL (2011) showed that for a conceptual model based on a homogeneous and isotropic hydrogeologic unit between the Alluvial Aquifer and the spring, which is not the case, that a maximum decline in groundwater levels at the spring would be about six feet after several hundred years. As noted, the updated hydrogeologic conceptual model shows more complex hydrogeology, including a hydraulic disconnect with upgradient units and faulting that will effectively preclude any effect at the spring from drawdown in the Alluvial Aquifer. Therefore, the Water Project will not have an impact on the Bonanza Spring. The spring's long-term sustainability is dependent on long-term average precipitation to provide recharge to its catchment and not downgradient conditions in the Alluvial Aquifer.

Figure 3-7 Projected Maximum Extents of 20-Foot Drawdown Contour From Cadiz Water Project After 50 Years



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