CUYAMA VALLEY GROUNDWATER BASIN (3-13)
BOUNDARY MODIFICATION REQUEST

TECHNICAL MEMORANDUM
April 3, 2018

Prepared for
GRAPEVINE CAPITAL MANAGEMENT

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CLEATH-HARRIS GEOLOGISTS
71 Zaca Lane, Suite 140
San Luis Obispo, California 93401
(805) 543-1413

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INTRODUCTION

This technical memorandum presents hydrogeologic information in support of a groundwater basin boundary modification request for the Cuyama Valley Groundwater Basin (DWR 3-13). The information presented in this memorandum has been prepared in accordance with California Department of Water Resources (DWR) requirements for boundary modifications contained in the California Code of Regulations, Title 23 (Waters), Division 2 (Department of Water Resources), Charter 1.5 (Groundwater Management), Subchapter 1 (Groundwater Basin Boundaries), Article 3 (Boundary Modification Categories), and the California Code of Regulations, Title 23 (Waters), Division 2 (Department of Water Resources), Charter 1.5 (Groundwater Management), Subchapter 1 (Groundwater Basin Boundaries), Article 5 (Supporting Information).

Within these codes, Article 3 (§ 342) outlines the types and requirements of boundary modifications available and Article 5 (§ 344) describes the type of information required to support a boundary modification request. This includes: (1) information on the requesting agency (§ 344.2), (2) list of agencies affected by the modification (CCR Title 23, 344.4, (3) description of the proposed boundary modification (§ 344.6), (4) local agency input (§ 344.8), (5) general information including a description of lateral boundaries, a graphical map of lateral boundaries, definable bottom, and a geographical map and GIS files illustrating the proposed sub-basin (§ 344.10), (6) a hydrologic conceptual model (§ 344.12), (7) a technical study supporting the presence of a boundary (§ 344.14), and (8) any necessary documentation for CEQA compliance (§ 344.18). This report is intended to satisfy the requirements of items 3, 5, 6, and 7 of this documentation.

The existing location and existing boundaries for the Cuyama Valley Groundwater Basin are illustrated in Figure 1. The DWR Bulletin 118 boundary for the Cuyama Valley Groundwater Basin (DWR 3-13) comes directly from four map sheets: the 1:250,000 scale Geologic Map of California: San Luis Obispo Sheet (Jennings 1958), the 1:250,000 scale Geologic Map of California: Santa Maria Sheet (Jennings 1959), the 1:250,000 scale Geologic Map of California: Bakersfield Sheet (Smith 1964), and the 1:250,000 scale Geologic Map of California: Los Angeles Sheet (Jennings and Strand 1969). The boundary with respect to these map sheets is illustrated in Figure 2.

Two modifications are proposed to the basin: a scientific external boundary modification and a scientific internal boundary modification. The proposed external modification would truncate a portion of the northwestern-most finger of the basin based on finer-scale geologic mapping which indicates water-bearing sediments in this area are not contiguous with the basin. This modification would remove areas that are hydraulically isolated from the basin mitigating the need to manage an area unrelated to the basin.

The proposed internal modification of the Cuyama Valley Groundwater Basin is based on a technical study of the Russell fault, and would allow for improved management of the basin in several ways. First, existing groundwater management programs including well monitoring, water quality monitoring, land subsidence observations, and groundwater modeling treat the Russell fault as a de-facto management boundary (Sweetkind et al. 2013, Hanson et al. 2015). Historically, only minimal monitoring and management has been conducted in the Cuyama Valley Groundwater Basin west of the Russell fault (the proposed Chalk Mountain Subbasin). Subdividing the basin will allow for monitoring and management programs to be implemented that would focus on this area.

Secondly, while extensive overdraft has been observed east of the fault (Sweetkind et al. 2013, Hanson et al. 2015) placing the basin in critical overdraft, these conditions do not appear to be present west of the Russell fault. Existing groundwater contouring east of the fault (Singer and Swarenski 1970, Sweetkind et al. 2013, Hanson et al. 2015) indicate the zone of depression does not extend to the proposed fault boundary. Evaluation of the fault indicates it is a strong barrier to flow, insulating the over-drafted eastern zone from the western basin (Chalk Mountain Subbasin). Additionally, structural evaluation of the proposed Chalk Mountain Subbasin indicates that, unlike the main Cuyama Valley Subbasin, it is highly compartmentalized by folding and faulting. Subdivision of the basin would allow for management of water levels that is appropriate to the compartmentalized nature of the zone rather than the shared (and over-drafted) conditions seen east of the proposed fault boundary.

Lastly, observed water quality west of the proposed boundary is better than water quality east of the boundary. This is partially a function of recharge source, but also reflects the variation of agriculture use on either side of the proposed boundary. West of the fault, agricultural use principally consists of vineyards and dryland grazing operations (DWR 1996). East of the fault, intensive agricultural operations (DWR 1996) have both high levels of water consumption, and high levels of salt infiltration due to evaporative agricultural use (SBCWA 1996, 2001) which led to declining water quality. Subdividing the basin would allow for management practices that preserve existing water quality, and that remediate declining water quality in the Cuyama Valley Subbasin.

The proposed naming of the Chalk Mountian Subbasin is based on documentation created by Dudek Environmental Consultants in support of an earlier boundary modification (internal and external) request. This request was denied on the basis that "1) it was not demonstrated that the Russell Fault is a hydrogeologic barrier to groundwater flow adequate to subdivide the basin (DWR 2016)" and "2) the external boundary modifications described in the USGS report did not consistently follow geologic contacts used to define units consistent with the alluvial basin definition (DWR 2016)." Internal boundary modifications proposed in this report largely follow the previously outlined bounds with additional scientific and technical evaluation to support the presence of a fault-based hydrogeologic barrier. As such, the previously proposed subbasin name has been maintained. The area east of the Russell fault contains the bulk of the Cuyama Valley floor, and the portions of the Cuyama Valley Groundwater Basin which have been most intensely evaluated. This provided the basis for the proposed Cuyama Valley Subbasin name.

DESCRIPTION OF PROPOSED BOUNDARY MODIFICATION (§ 344.6)

Overview of Request for Boundary Modification (§ 344.6(a))

The proposed scientific, external boundary modification would remove a portion of an existing finger in the northwest portion of the basin. The new proposed boundary follows a fault previously mapped on the 1:250,000 scale Geologic Map of California: San Luis Obispo Sheet (Jennings 1958). Coarse-scale mapping (1:250,000) indicates water-bearing sediments exist on both sides of this fault. However, fine-scale mapping (1:24,000) shows that this fault juxtaposes nonwater-bearing sediments against water-bearing sediments. Water-bearing Morales Formation north of the newly proposed boundary is fault-isolated and surface water that drains from this area does not enter the basin. As such, it is proposed that that existing basin boundary be modified to remove the area north of this fault from the basin.

The proposed internal boundary modification would divide the existing Cuyama Valley Groundwater Basin into two subbasins along the Russell fault as mapped on the 1:250,000 scale Geologic Map of California: Bakersfield Sheet (Smith 1964), and the 1:250,000 scale Geologic Map of California: Los Angeles Sheet (Jennings and Strand 1969) (Figures 1 and 2). This modification is based on fault offset, fault sealing capacity, water level data, spring data, and water quality measurements, as is further discussed in this report. This data demonstrates that the fault is a regional barrier to flow within the basin.

<u>Category of Proposed Boundary Modification (§ 344.6(a)(1))</u>

California Code of Regulations, Title 23 (Waters), Division 2 (Department of Water Resources), Charter 1.5 (Groundwater Management), Subchapter 1 (Groundwater Basin Boundaries), Article 3 (Boundary Modification Categories) discusses the various types of basin boundary modifications and the requirements for each modification type. Pursuant to statute §342.2(b) two modifications are proposed: a scientific, external boundary modification, and a scientific, internal boundary modification. This statute states that "a basin or subbasin boundary may be modified, deleted, or added based on the presence or absence of a hydrologic boundary." These modifications would first remove hydraulically isolated sediments currently included in the basin, and secondly would divide the existing Cuyama Valley Groundwater Basin into two subbasins based on the presence of an internal hydrologic boundary (barrier to flow).

<u>Identification of all Affected Basins or Subbasins (§ 344.6(a)(2))</u>

The affected basin would be the Cuyama Valley Groundwater Basin (DWR 3-13).

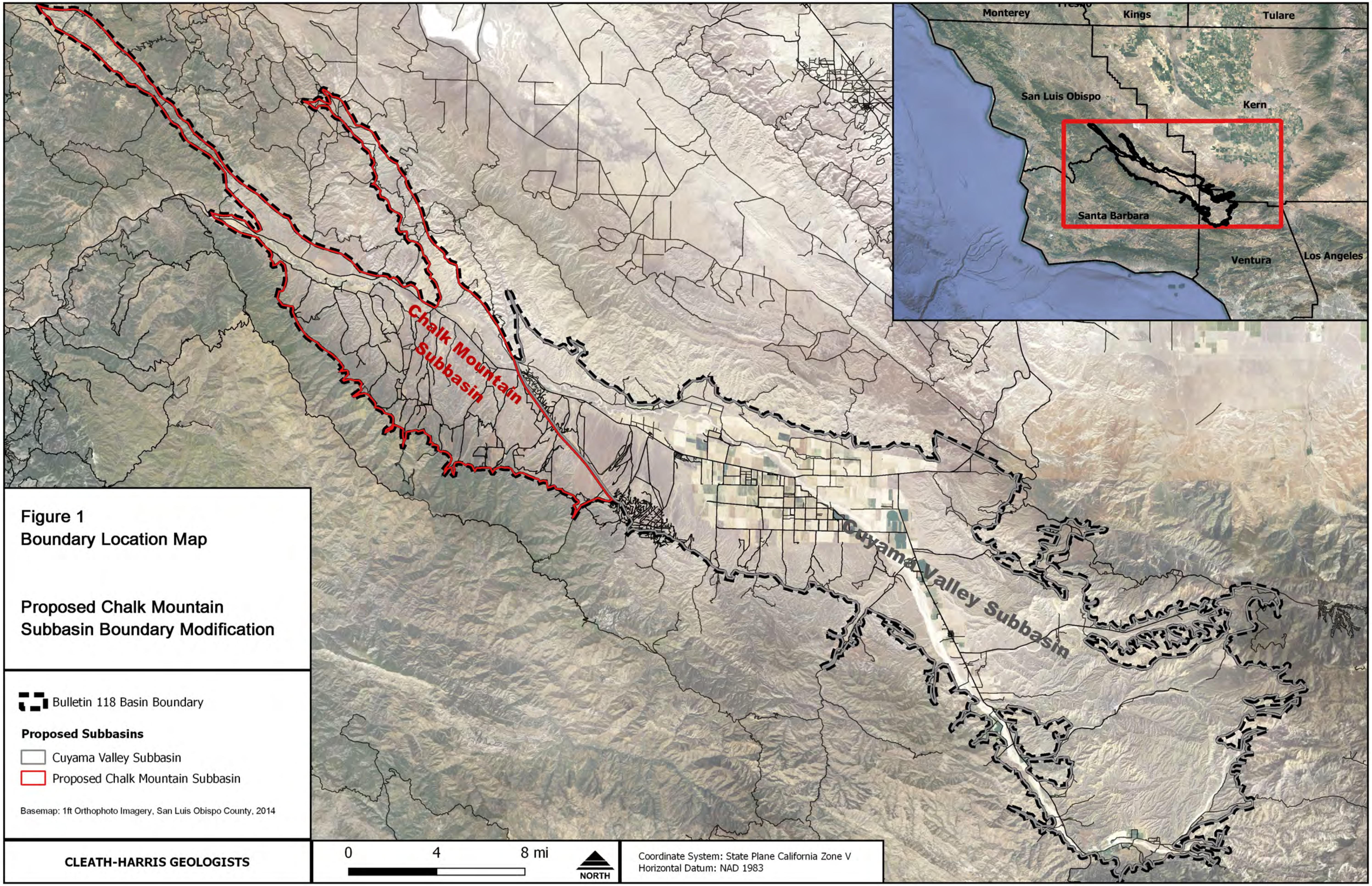

Figure 1
Boundary Location Map

Proposed Chalk Mountain Subbasin Boundary Modification

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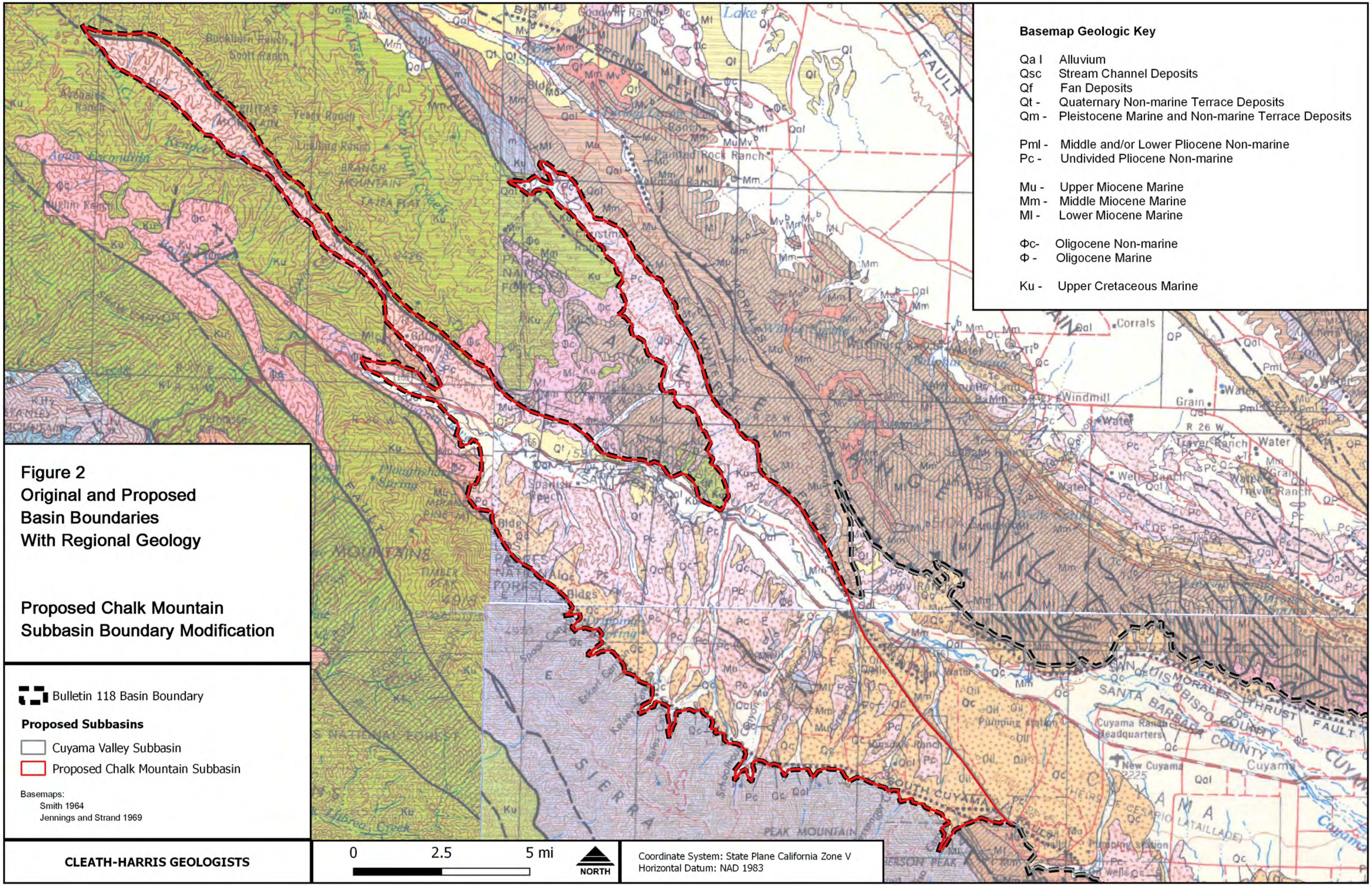

Figure 2
Original and Proposed Basin Boundaries With Regional Geology

Proposed Chalk Mountain Subbasin Boundary Modification

Proposed name for each new subbasin (§ 344.6 (a)(3))

The proposed scientific, internal boundary modification would divide the existing Cuyama Valley Groundwater Basin into two subbasins. The proposed name for the western subbasin is the Chalk Mountain Subbasin and the eastern subbasin is proposed to be named the Cuyama Valley Subbasin.

GENERAL INFORMATION (§ 344.10)

Description of lateral basin boundaries and definable bottom (§ 344.10(a))

Lateral Basin Boundaries

The Cuyama Valley Groundwater Basin underlies an east-west trending synclinal valley that is largely fault bounded. Figure 2 illustrates the relationship between underlying geology and the existing basin boundaries. To the north, the basin is bounded by the Cuyama fault, Whiterock/Russell fault, and the Morales fault. Locally, alluvial fingers extend beyond the fault bounds. In the west, the basin is truncated by the Cuyama, Chimeneas, La Panza, and South Cuyama faults as well as by unnamed faults associated with these fault systems. To the south, the South Cuyama, Ozena and Big Pine faults truncate permeable sediments with only localized fingers of alluvium extending past them. In the east, the basin is bounded by older sediments uplifted along the greater San Andreas fault zone and San Emigidio Mountains (Upson and Worts 1951, Singer and Swarzenski 1970, Everett et al. 2013).

Definable Bottom

The definable bottom of the basin corresponds to the bottom of the Morales Formation (Upson and Worts 1951, Singer and Swarzenski 1970, DWR 1998).

Graphical Map of lateral basin boundaries (§ 344.10(b))

Figure 1 is a map illustrating the existing lateral boundaries of the Cuyama Valley Groundwater Basin (DWR 3-13). This map illustrates existing basin boundaries, and the proposed external boundary modification which would alter lateral basin boundaries. It also illustrates the proposed subbasin boundary.

HYDROGEOLOGIC CONCEPTUAL MODEL (§ 344.12)

Principal Aquifers and Regional Aquitards (§ 344.12(1))

The principal aquifer and aquitards were first described by Upson and Worts (1961). Water-bearing units include modern alluvium, older alluvium, fanglomerate (terrace) deposits, and the underlying Upper Morales Formation. Alluvium and older alluvium were lumped by Upson and Worts but have subsequently been differentiated. The lower Morales Formation is fine grained and is generally an aquitard within the basin. The base of the freshwater-bearing sediments has historically been defined as the bottom of the Morales Formation, largely for water quality reasons (Upson and Worts 1951, Singer and Swarzenski 1971).

Alluvium

Younger alluvium is Holocene in age and consists of sand, gravel and silt deposits which have been deposited in the past 1,000 years (DeLong et al. 2011). Deposits are located within the incised channel of the Cuyama River with fingers running up the floors of tributary canyons and washes. Deposits are generally less than 100 feet thick and overlie both older alluvial deposits and terrace deposits. Upson and Worts note that layers are not laterally extensive, but generally consist of layers of sand and clay several feet thick inter-bedded with clays in beds one to thirty-six feet thick. Deposits of alluvium are generally coarser in the eastern portions of the basin and fine westward. Historically, water was only produced from the alluvium in the western portions of the valley and the Cuyama River Valley upstream of the Santa Barbara Canyon fault, as water levels were below these deposits in the central portion of the basin.

Older Alluvium

Older alluvial deposits in the Cuyama River Valley are also Holocene ranging in age from 3000-2000 years before present (b.p.). These deposits can widely be broken into three major deposits which Delong et al. labeled D1, D2, and D3. D1 is the oldest of these deposits and D3 is the youngest. Deposits of D1 and D2 are massive fine sands and silts in thin to medium lenticular beds. Unit D3 deposits are fines sands, gravels and cobbles in tabular beds. Little to no soil development has occurred on D3 deposits. The D1-D2 surface and the D2-D3 surface are demarked by paleosols (DeLong et al. 2011).

Fanglomerate/Terrace Deposits

Piedmont and fan and terrace deposits are mid-to-late Pleistocene in age and flank the Cuyama River on both sides of the valley. They are particularly apparent to the south where they cap the highlands between the Sierra Madre Mountains and the Cuyama River plain. Extensive work by DeLong et al. 2007 characterized these terrace deposits in the area adjacent to the proposed subbasin boundary.

This research delineated the terrace deposits into seven subgroups (Q1-Q7) plus underlying bedrock. These deposits sit unconformably on the Morales Formation (which crops out as topographical highs throughout the piedmont surface). Within these deposits, Q1 is undifferentiated alluvial deposits, Q2-Q6 are fanglomerate deposits (where lower numbers represent older ages), and Q7 is late Holocene older alluvium. All deposits are clast-supported sands, gravels and boulders. Surfaces are separated by thin paleosols and thin deposits of aeolian sands. Surfaces Q2 and Q3 (which are the oldest) are also the highest lying in the sequence with surfaces Q4-Q6 as infill of eroded zones in the older surfaces (Delong et al. 2007). DeLong et al. also mapped QTmol as fine-grained (lacustrine) deposits of the Morales, QTm as coarse grained Morales Formation, and Qyp as palustrine deposits and TR as Pre-Pliocene bedrock.

Studies of the terrace deposits indicate thrusting along the Whiterock fault created displacement in the Sierra Madre terraces for Units Q2 and Q3 (Vedder et al. 1994, DeLong et al 2008). This places the latest displacement age for the zone at between 45,000 years (Q3 age) and 30,000 years (Q4 age) b.p. (DeLong et al. 2007).

Approximately 20,000 year b.p., the basin underwent a transition from a depositional regime to an erosional regime. Incisement of drainages emanating from the Sierra Madre Mountains (including Aliso, Schoolhouse, and Cottonwood Canyons) occurred at this time and continued until the onset of deposition of older alluvial material some 3000 years b.p. (DeLong et al. 2007). In general, terrace deposits lie above both existing drainages and the water table in the area surrounding the proposed internal boundary.

Upper Morales Formation (Tmo-u)

The Morales Formation is Plio-Pleistocene in age and is generally a series of sands, gravels, and cobbles, with interbedded clays and silts. These deposits are mapped by Dibblee as the upper Morales (Tmo-u). To the west, extensive fine-grained lacustrine deposits are found in significant segments of the basin (DeLong 2008), at or below the boundary of this upper interval.

Lower Morales Formation (Tmo-l)

The lower Morales is generally a claystone with limited interbedded clayey sands (Tmo-l). This unit is the most significant aquitard within the water-bearing sediments of the Cuyama Valley Groundwater Basin. This is clearly illustrated in the NF #4 well where the top 800 feet of formation is coarse-grained material (Tmo-u), and the bottom 400 feet was fine-grained material (Tmo-l) (Figure 3, Figures 19-22). These fine-grained sediments generally extend to the Quatal Formation west of the fault (as is seen in mud-logs for API 08321325). East of the Russell fault, while the formation generally coarsens upward, a basal gravel/cobble has been locally observed at the Morales Formation contact with the Quatal Formation. The Lower Morales lies conformably on the Quatal Formation and unconformably on underlying marine sediments.

Lateral Boundaries (§ 344.12(2))

Lateral boundaries for the proposed external basin boundary modification follow all the existing Bulletin boundaries except in the vicinity of Gifford Ranch. Just northeast of the ranch the existing boundaries are truncated by a northward trending fault (Figure 3 and Figure 4). This fault represents the maximum extent of basin connected water-bearing sediments. Outcrops of Morales Formation north of this point are isolated by fault movement along the La Panza fault system.

Lateral boundaries for the proposed internal boundary modification are largely defined by faults which uplift deeper, older, nonwater-bearing sediments against younger water-bearing sediments. While boundaries on the map are depicted as linear features, these faults are, in reality, complex zones comprised of multiple fault strands and associated small-scale structures. From a conceptual standpoint this makes boundary zones both wider and less distinct than can be accurately depicted on a map. Based on oil well locations and mapped fault splays, the greater Russell fault zone extends at least 3,000 feet east and 1,000 feet west of the fault location mapped by Smith, Jennings, and Strand. Figure 3 shows the Russell fault locations (zone) as mapped by Dibblee, Smith, and Jennings and Strand and Figures 13 and 14 illustrate some of the documented strands associated with the fault zone. The variation in the mapped position of the fault illustrates the uncertainties that are associated with a zone rather than a single fault strand. For purposes of boundary modification the strand mapped by Smith (1965) and Jennings and Strand (1969) was used to delineate the subbasins. These maps also were the basis for the original Bulletin 118 boundary for the basin, as is shown in Figure 2.

Cuyama Valley Subbasin

The proposed Cuyama Valley Groundwater Subbasin is largely fault-bounded. Figure 2 illustrates the relationship between underlying geology and the existing basin boundaries. To the north, the basin is bounded by the Whiterock fault, and the Morales fault. Locally, alluvial fingers extend beyond fault bounds. In the west, the subbasin is truncated by the Russell/Whiterock Fault System. To the south, the South Cuyama, Ozena and Big Pine faults truncate permeable sediments with only localized fingers of alluvium extending past them. In the east, the subbasin is bounded by older sediments uplifted along the greater San Andreas fault zone and San Emigidio Mountains.

Chalk Mountain Subbasin

The proposed Chalk Mountain Subbasin is also largely fault bounded (Figure 2). To the north, the basin is bounded by the Cuyama fault, and the Whiterock/Russell faults. Locally, alluvial fingers extend beyond fault bounds. In the west, the basin is truncated by unnamed faults associated with

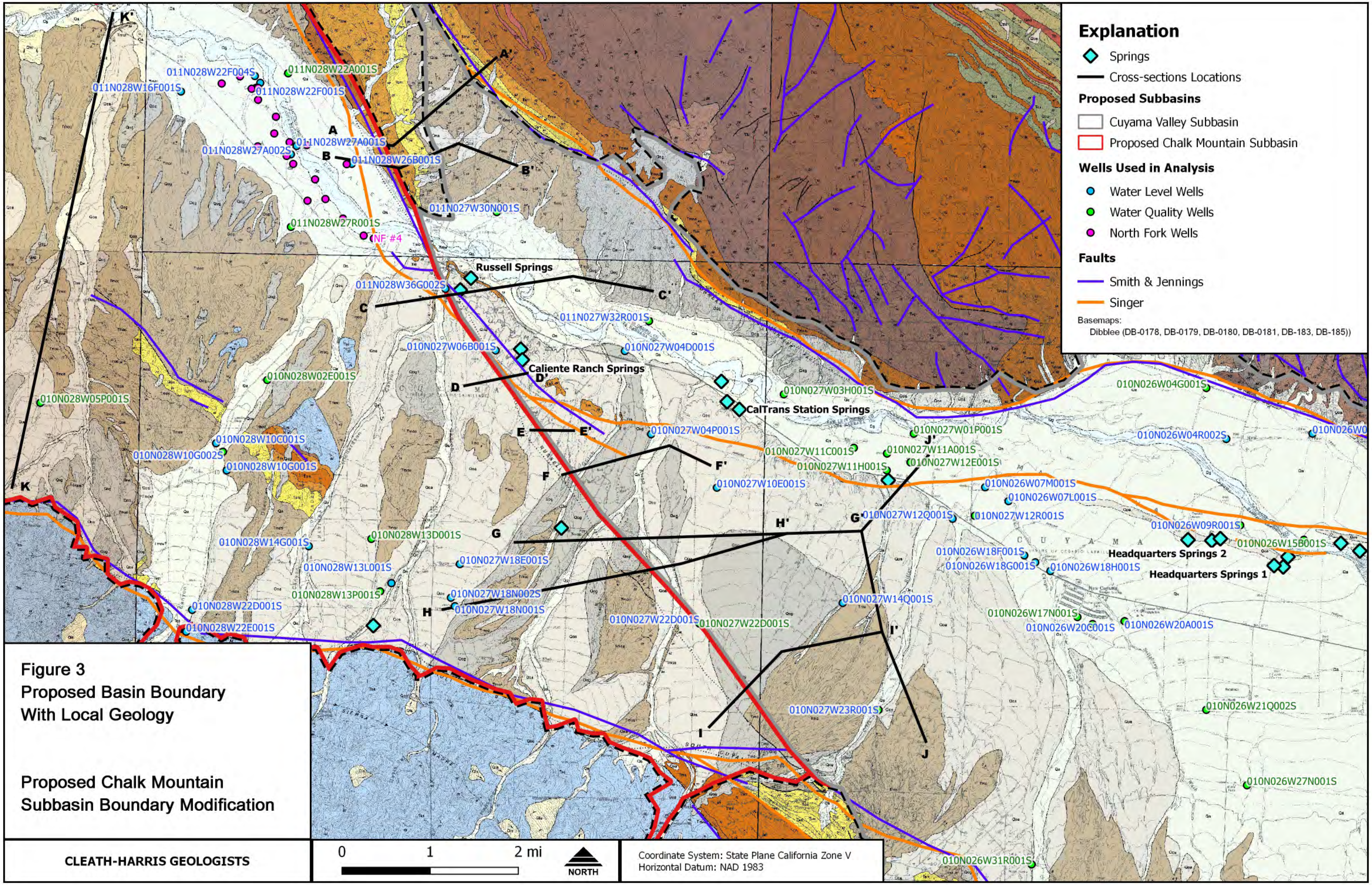

Figure 3
Proposed Basin Boundary
With Local Geology

Proposed Chalk Mountain
Subbasin Boundary Modification

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the Cuyama, Chimineas, La Panza, and South Cuyama fault systems. To the south, the South Cuyama, fault truncates permeable sediments with only localized fingers of alluvium extending past it. In the east, the subbasin is bounded by the Whiterock/Russell fault zone.

Geologic Features Impacting Groundwater Flow (§ 344.12(2)(A,B,C))

Features which impact groundwater flow within the basin include lateral bounding faults, synclinal structures, and internal faults which have been documented to retard or restrict groundwater flow. A fuller description of these features follows.

Cuyama Valley Subbasin

Within the Cuyama Valley Subbasin, faults bound the subbasin restricting subsurface flow (which are treated as no-flow boundaries by the USGS for basin modeling). These include the Russell fault, Whiterock fault, the Morales fault, the South Cuyama fault, and the Ozena fault.

The Cuyama Valley Subbasin has been extensively evaluated by the USGS as part of ongoing monitoring of the Cuyama Valley Groundwater Basin. These evaluations have identified a number of internal faults which restrict or retard flow including the Graveyard fault, Turkey Trap Ridge fault, the Rehoboth fault, and the Santa Barbara Canyon fault (Everett et al. 2013, Sweetkind et al. 2013, Hanson et al, 2015). Historic seeps and springs have been noted near the trace of the Turkey Trap Ridge and Graveyard faults (Upson and Worts 1951). Additionally, asymmetrical water level draw downs of 80-100 feet were noted across these faults (Singer and Swarenski 1970). The Santa Barbara Canyon fault has been associated with steep hydraulic gradients moving south to north into the basin. The last fault, the Rehoboth fault, was initially inferred from lateral water level changes within the basin.

These subsurface flow barriers led to the division of the eastern basin (Cuyama Valley Subbasin) into nine subregional hydrologic zones (Figure 7). These zones "separate the aquifers into regions that are fault bounded and where the response to the use movement, and consumption of water is similar in specific parts of the aquifers, but differs from the other zones (Everett et al. 2013)." These zones have subsequently been used for water level and water quality monitoring and evaluation as well as for groundwater monitoring (Sweetkind 2013, Hanson 2015). It should be noted that the USGS evaluation area does not fully follow the Bulletin 118 basin definition and, as such, USGS management areas in the proposed Cuyama Valley Subbasin do not encompass all areas of the basin (Figure 7).

Chalk Mountain Subbasin

Geologic features which impact groundwater flow within the subbasin include faults and a series of synclinal structures created by en echelon folding. Major faults bound the subbasin as previously discussed, including the Russell fault, Cuyama fault, and South Cuyama fault. These bounding faults create no-flow (or highly restricted flow) bounds to the basin. An additional internal fault (currently unnamed) has been mapped between Schoolhouse Canyon and Cottonwood Canyon (Dibblee DF-0181, DF-0183, DF-0185, DF-0265), Smith 1964, Jennings and Strand 1969, DeLong et al 2007). This fault folds older, nonwater-bearing sediments to the surface in a syncline, creating a small compartment against the Sierra Madre Mountains (Figures 6 and 18). While the trace of this unnamed fault is not well constrained, sharp reversals in dips and the presence of springs suggest this fault carries to the western basin boundary (Figure 6). Water levels drop sharply across this bound (Figure 23) and differential water levels have been reported across the fault in converted oil wells in T11N/R28W on the eastern side of Cottonwood Wash.

Additionally, within the subbasin, a series of en echlon folds create a number of small synclinal structures that compartmentalize permeable sediments within the subbasin. These synclines bring impermeable basal sediments of the Morales Formation (Tmo-l) to the surface compartmentalizing the producible groundwater zones. These synclines roughly trend subparallel to the main axis of the basin. These include the syncline in upper Green Canyon (Dibblee, DF-0181), the Ruby Star Syncline (Figure 6) which was mapped with subsurface data associated with the North Forks Ranch Wells (Group 4, Figure 26), and a poorly defined syncline on Spanish Ranch (Dibblee, DF-0265 and DF-0183)).

Two long fingers extend northward from the main subbasin and are controlled by faults, including the Chimeneas Ranch area (Figure 2 and 3). The Chimeneas Ranch area is principally composed of Morales Formation, which lies between the Whiterock fault and portions of the San Juan fault. This zone is bisected by numerous drainages which largely cross from northeast to southwest, which carry water out of the basin, before it re-enters the basin near the Cuyama River. Small structures which run parallel or sub-parallel to the Whiterock fault can be found in this finger. The second finger, which begins near the Gifford Ranch and trends to the northwest, contains isolated splays of Morales Formation that crops out against the La Panza fault. These zones are discontinuous with the basin north of a fault splay near Gypsum Creek and all drainages emanating from this northern area carry water out of the designated basin. Only the area near Gifford Ranch, including Gypsum Creek, Sycamore Creek and several smaller unnamed tributaries, is in hydrologic contact with the basin (Figure 4 and Figure 5). The proposed external boundary modification would remove the discontinuous zones from the subbasin.

For management purposes the subbasin can be divided into five sub-regional hydrologic zones: the West Uplands Zone, the Green Canyon Zone, the Ruby Star Zone, the Spanish Ranch Zone and the Chimeneas Ranch Zone as shown in Figure 7.

<u>The West Uplands Zone</u> runs southeast to northwest and roughly parallels the South Cuyama fault. The northern boundary of this zone follows a fault in the far eastern and far western portions, and follows a zone of dip reversals (either an anticline or fault trend) where it parallels the Spanish Ranch Zone. Sediments in this zone appear to be folded into a syncline with Santa Margarita

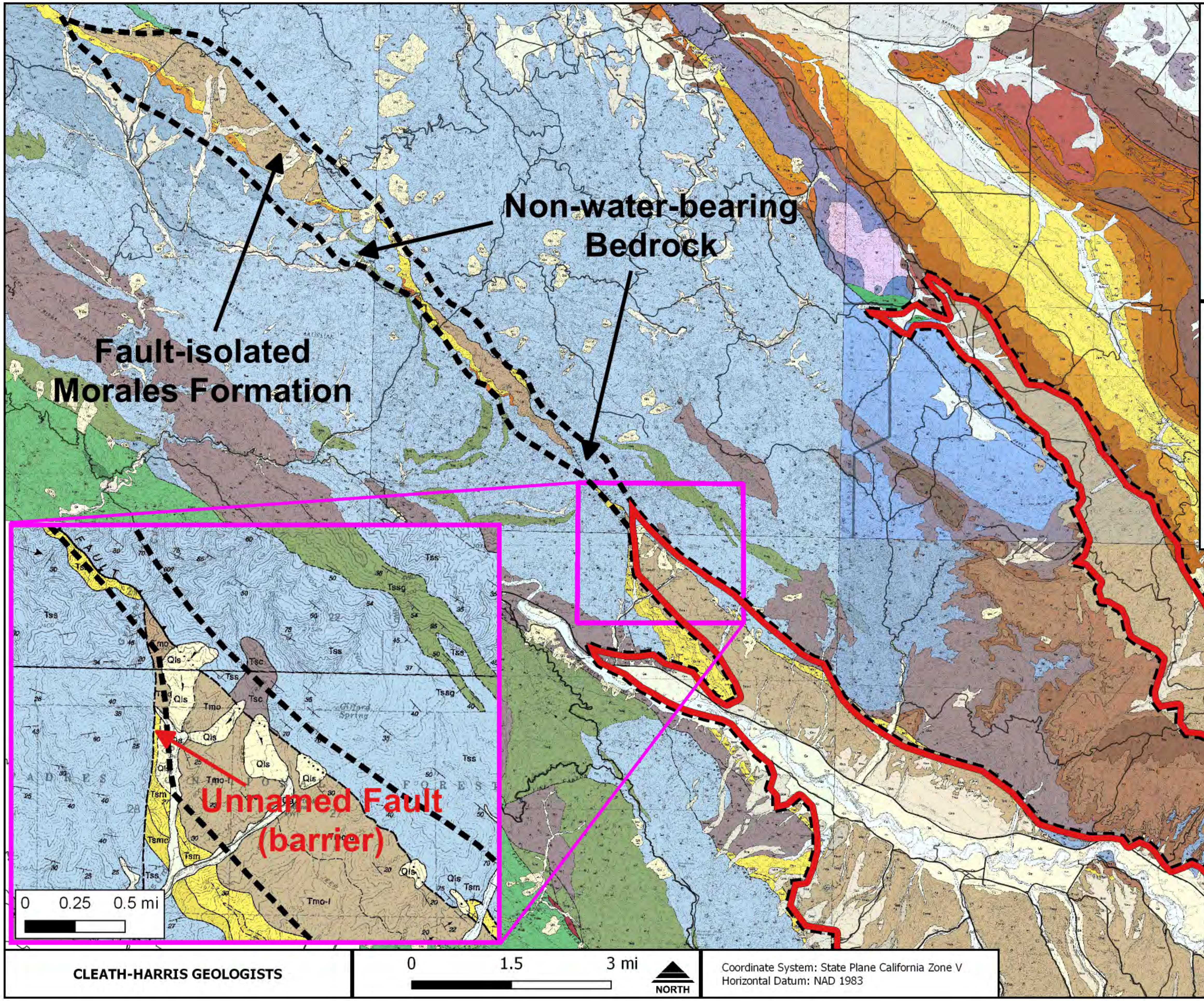

Figure 4
Geology of
Proposed External
Boundary Modification

Cuyama Valley
Groundwater Basin

Proposed Chalk Mountain
Subbasin Boundary Modification

Explanation

Bulletin 118 Basin Boundary

Proposed Chalk Mountain Subbasin

Basemaps:
Dibblee
(DB-0099, DB-0183, DB-0262, DB-0263, DB-0265)

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Coordinate System: State Plane California Zone V
Horizontal Datum: NAD 1983

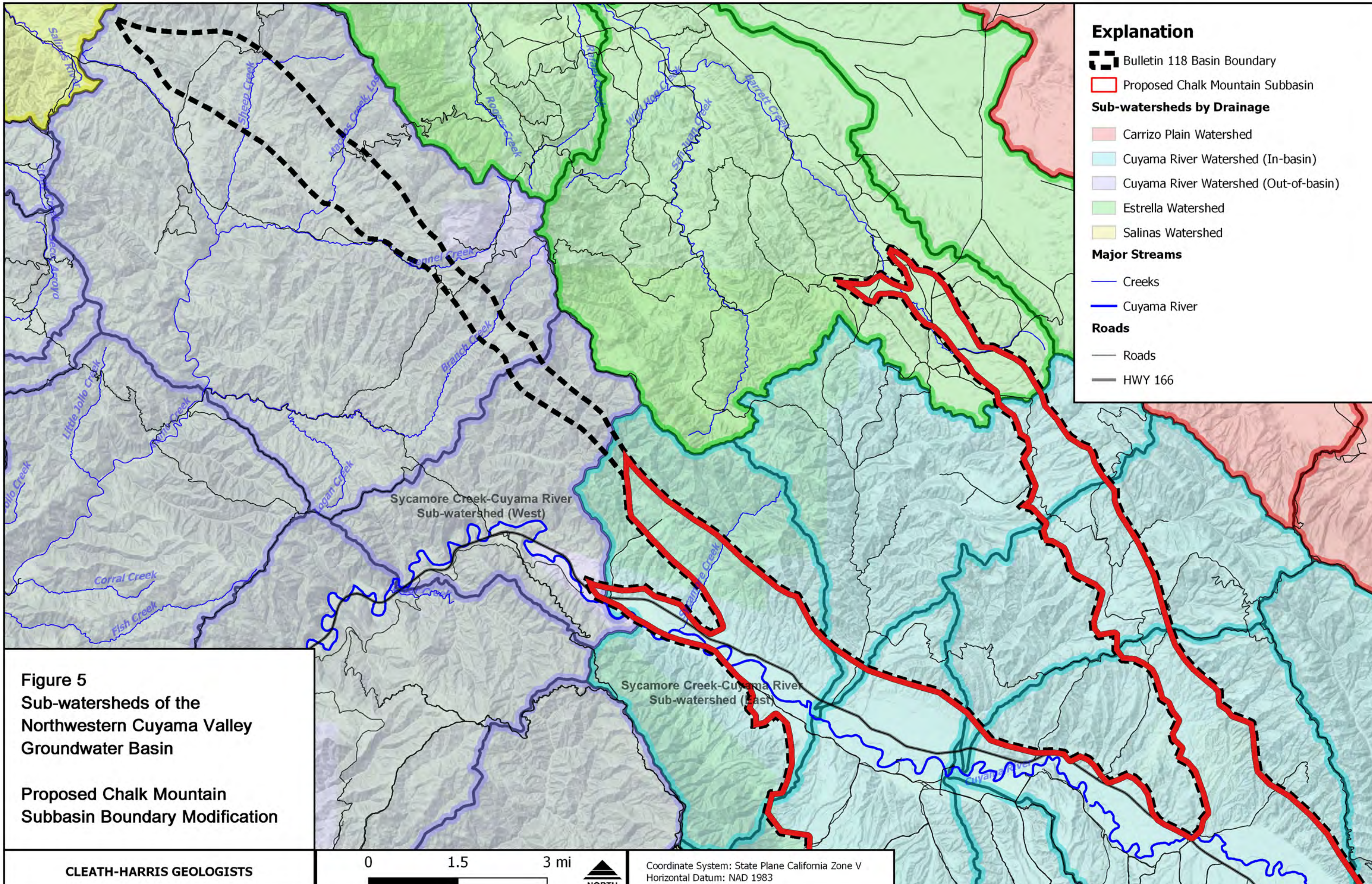

Figure 5
Sub-watersheds of the Northwestern Cuyama Valley Groundwater Basin

Proposed Chalk Mountain Subbasin Boundary Modification

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Coordinate System: State Plane California Zone V
Horizontal Datum: NAD 1983

Formation bounding both sides of the zone (Figure 6). Water produced within this zone is serves rural residences and small farming operations. A number of wells have been historically monitored by the USGS in this zone and could be used for future monitoring (Figures 23 and 25). Recharge is principally from infiltration along ephemeral drainages emanating from the Sierra Madre Mountains.

The Green Canyon Zone contains a syncline trending southeast to northwest between the Russell fault and the unnamed fault which bounds the West Upland Zone. The remaining boundary is the drainage divide between Richardson and Schoolhouse Canyons, where marine bedrock crops up near the surface. Water use in this zone is limited to a few homes and small farming and grazing operations. One well has been historically monitored in this zone and could be used for future management. Recharge is principally from infiltration along ephemeral drainages emanating from the Sierra Madre Mountains.

The Ruby Star Zone contains a syncline which trend sub-parallel to the Whiterock fault. It is bounded by the Whiterock/Russell fault on the east, as well as by a small anticline and the drainage divide between Richardson and Schoolhouse Canyons. To the south, an unnamed fault creates boundary and to the west, a bedrock high bounds the zone. The edge of the older alluvium is the northern boundary for this zone (Figure 6). Several historic monitoring wells exist in the zone, but these wells only penetrate shallow alluvium rather than bedrock. This zone is currently extensively planted in vineyards and has higher production and use than other portions of the proposed Chalk Mountain Subbasin. Recharge is through infiltration from the Cuyama River and from infiltration along ephemeral drainages emanating from the Sierra Madre Mountains.

The Spanish Ranch Zone is bounded in the east by a bedrock high and the drainage divide west of Cottonwood Canyon. To the south, it is bounded by an unnamed fault. To the west, it is bounded by segments of the South Cuyama and La Tallade faults. To the north, the zone is bounded by the La Panza fault. Water use in this zone is for grazing and cattle operations and a few residences. Recharge in this zone is through infiltration from the Cuyama River and from infiltration along ephemeral drainages emanating from the Sierra Madre and Caliente Mountains. No monitoring wells are known in this area.

The Chimeneas Ranch Zone extends northward from the Ruby Star Zone to the northern edge of the basin. This zone is bounded in the east by the Whiterock fault and in the west by the edge of Morales formation sediments. Only minimal groundwater production associated with the Chimeneas Ranch exists in this zone and no historic monitoring wells were located in the zone. Recharge is principally from infiltration along small ephemeral drainages emanating from the Caliente Mountains.

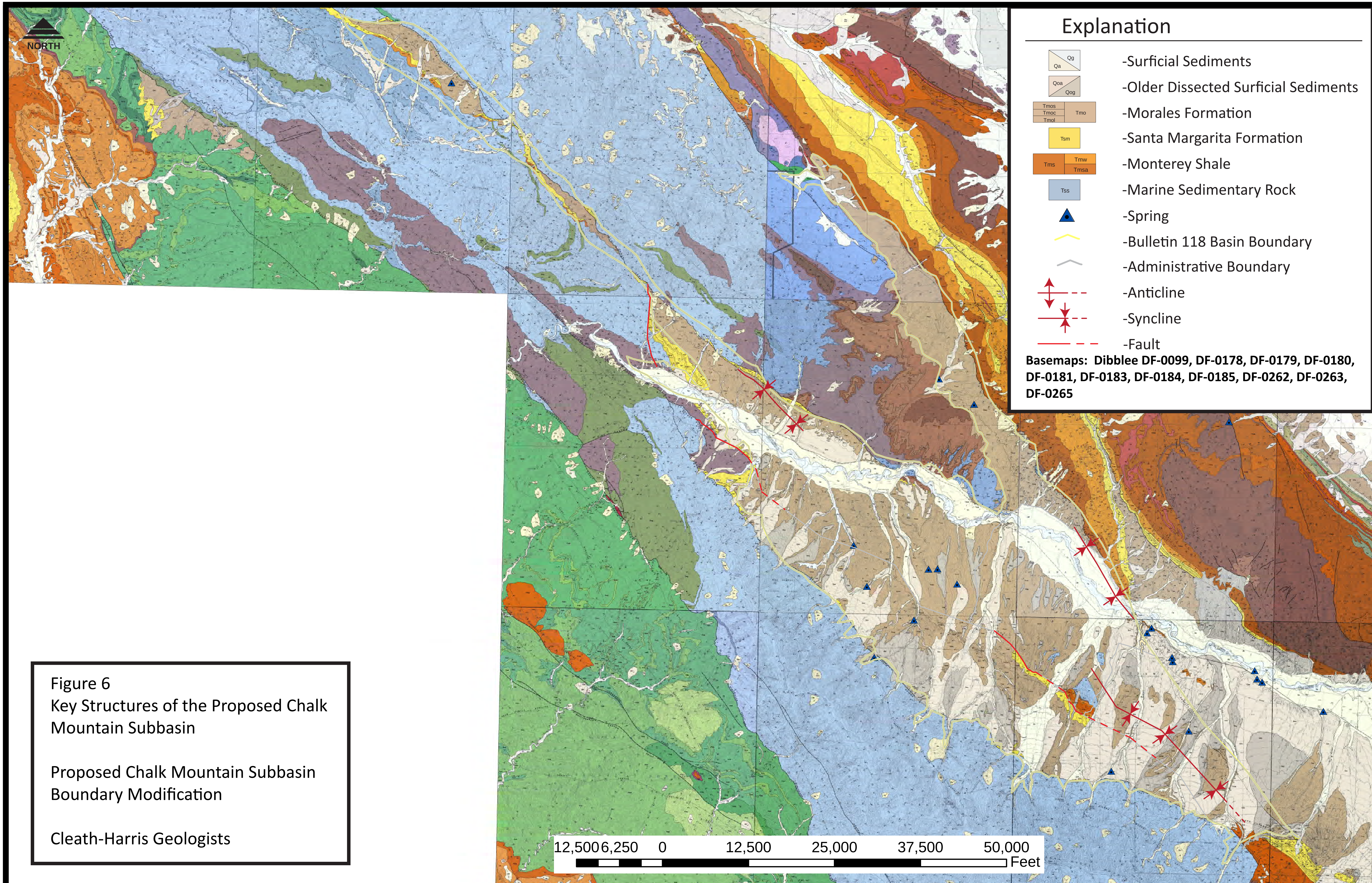


Figure 6
Key Structures of the Proposed Chalk Mountain Subbasin

Proposed Chalk Mountain Subbasin Boundary Modification

Cleath-Harris Geologists

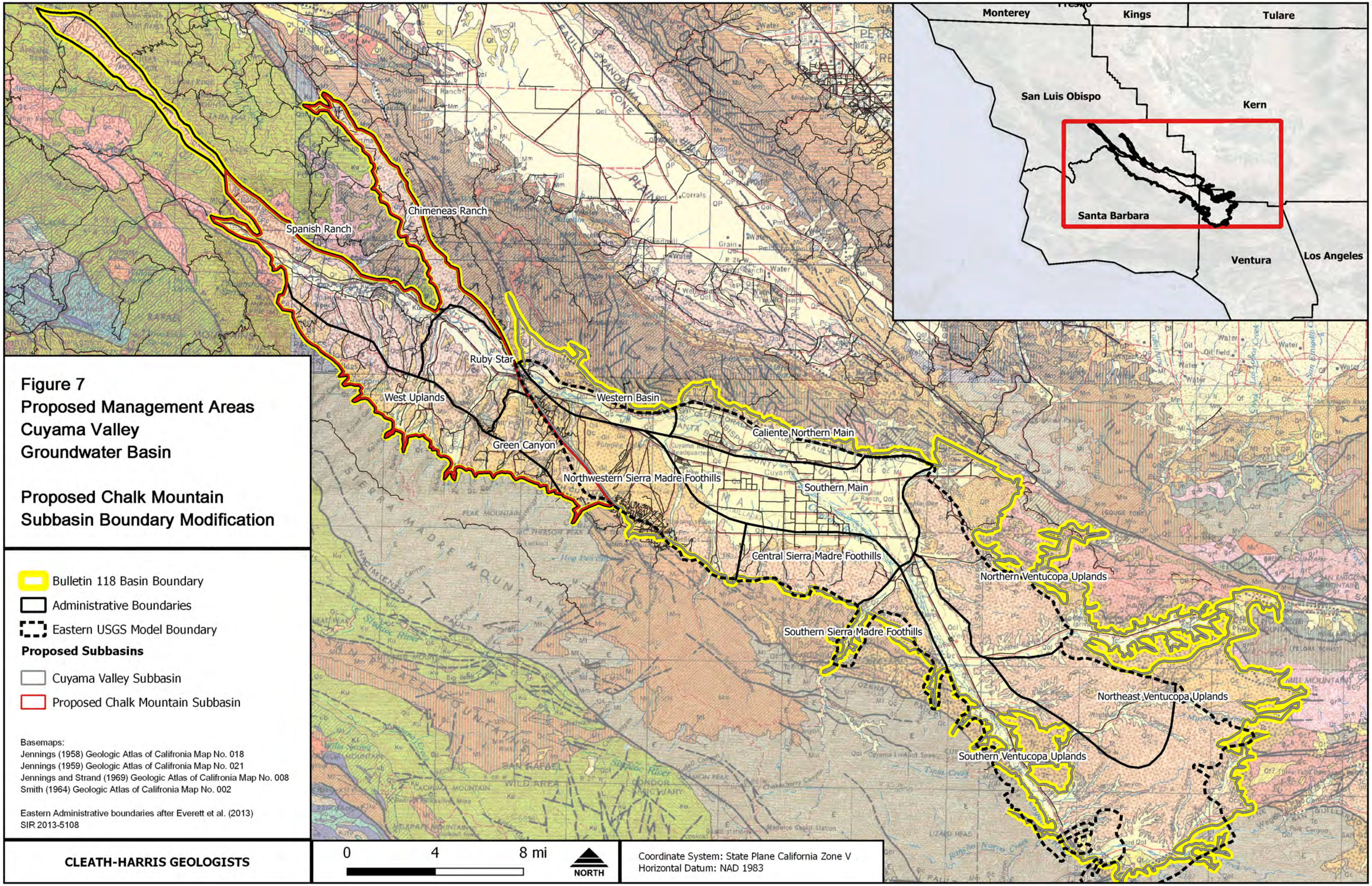


Figure 7
Proposed Management Areas
Cuyama Valley
Groundwater Basin

Proposed Chalk Mountain
Subbasin Boundary Modification

Key Surface Water Bodies and Significant Recharge Sources (§ 344.12(2)(D))

Surface water bodies within the basin are limited to the Cuyama River and ephemeral streams emanating from the Sierra Madre, Caliente and San Emigdio Mountains. Locally, within the basin, both year-round and seasonal springs occur, although many of the historically noted springs have dried up with declines in basin water levels (English 2016, Upson and Worts 1951, Singer and Swarzenski 1970, Delong et al. 2007, Everett et al. 2013, Hanson et al. 2015).

Basin recharge comes from various sources including rainfall, infiltration from the Cuyama River, runoff and infiltration from ephemeral streams emanating from the Sierra Madre, Caliente and San Emigdio Mountains and applied irrigation water return flow. All of these sources have different hydro-geochemical signatures, with water from the river and Caliente Ranges being particularly brackish (Singer and Swarzenski 1970). Little recharge comes into the basin as subsurface inflow from bedrock or underflow as the faults which bound the basin act as a barrier to such flow (Hanson et al 2015).

Recharge and Discharge Areas (§ 344.12(3))

Basin recharge comes from various sources including rainfall, infiltration from the Cuyama River, runoff and infiltration from ephemeral streams emanating from the Sierra Madres, Caliente and San Emigdio Mountains. All of these sources have different hydro-geochemical signatures, with water from the river and Caliente Ranges being particularly brackish (Singer and Swarzenski 1970). Recharge from these brackish zones tends to degrade water quality in the main basin and in the proposed sub-basin (which were historically charged from the Sierra Madre Mountains). Little recharge comes into the basin as deep percolation or underflow, as the faults which bound the basin act as a barrier to such flow (Hanson et al 2015).

Precipitation varies greatly across the basin, but generally is higher in upland areas and lower on the valley floor. Precipitation averages 8 inches a year on the valley floor (as measured at Cuyama and New Cuyama), 19 inches per year in the southern Ventucopa Uplands (Figure 7) and 12 inches per year around Santa Barbara Canyon. No long-term gauging data exists in the proposed Chalk Mountain Subbasin but trends would be expected to be similar with higher rainfalls in the uplands than on the valley floor near the river. Precipitation that does not infiltrate into the basin runs off, eventually joining the Cuyama River and discharging out of the basin (Everett et al 2013).

Runoff from the surrounding mountains flows into the basin along several major drainages. In the proposed Cuyama Valley Subbasin these include the Reyes Creek, Quatal Canyon and Apache Canyon drainages, which emanate from the San Emigdio Moutains. They also include Rancho Nuevo Creek, Pato Canyon, Santa Barbara Canyon, Goode Canyon, Castro Canyon, Salisbury Canyon, Aliso Canyon and Wells Creek drainages which emanate from the Sierra Madre Mountains. Drainages sourcing in the Caliente range are generally smaller and include, Horse

Canyon, Sulphur Canyon, Padrones Canyon and other smaller drainages. Water carried into the basin in these drainages, that does not infiltrate, discharges in the Cuyama River.

In the proposed Chalk Mountain Subbasin, drainages that bring water in from the surrounding highland mountains watersheds include the drainages of Green Canyon, Schoolhouse Canyon, Cottonwood Canyon, Kelly Canyon, Mustang Canyon and Miranda Canyons, all of which emanate from the Sierra Madre Mountains. From the north, Sycamore Canyon, Carrizo Canyon, Taylor Canyon and Morales Canyon all bring water from the Caliente Mountains into the basin when precipitation is sufficient for runoff. Water that does not recharge the basin joins the Cuyama River and discharges from the basin.

The Cuyama River acts as both a source of recharge and discharge for the basin. Major drainages feed the river carrying runoff from upstream areas in the east and the highland areas that surround the basin westward along the valley. Water that does not infiltrate from the river is discharged out of the basin at its western boundary.

Additional discharge occurs in numerous small springs scattered throughout the Basin (Figures 3 and 6) although many of the historic springs are now dry (Hanson et al. 2015).

The last major source of net discharge is agricultural irrigation. Agricultural use is scattered throughout the basin, but is most intense in the proposed Cuyama Valley Subbasin, particularly on the valley floor between New Cuyama and the juncture of Highway 33 with Highway 166. Additionally, the area bordering Highway 33 near Ventucopa has high levels of agricultural water use (DWR 1996).

In the west, within the proposed Chalk Mountain Subbasin, agricultural water use is highest around the vineyards associated with the Ruby Star Zone. Other zones see only light domestic use or limited use associated with ranching and dry-land farming (DWR 1996).

Definable Bottom of the Basin or Subbasin (§ 344.12(4))

The definable bottom of the basin corresponds to the bottom of the Morales Formation. Under most of the basin this contact is associated with the Quatal Formation. Marker beds for this contact are readily identifiable in logs (Sweetkind 2013, Figures 8-17). Depths for this contact range from surface (0 feet) to 5,000 feet below ground surface, but are generally around 600 foot depth (Upson and Worts 1951, Singer and Swarzenski 1970, Sweetkind et al 2013). This definition applies to both the proposed Cuyama Valley Subbasin and the Chalk Mountain Subbasin.

TECHNICAL INFORMATION FOR SCIENTIFIC MODIFICATION (§ 344.14)

Aquifer Extent (§ 344.14 (a))

Map of lateral boundaries of aquifers that define the basin and subbasins (§ 344.14 (a)(1))

A regional scale map of the basin as it relates to principal aquifer units is included in Figure 2. This map shows the lateral extent of the water-bearing sediments, the truncating fault that is the basis for the proposed external basin boundary modification. Additionally, it shows the Russell fault which, as illustrated on this regional map, provides the basis for the proposed scientific internal boundary between the two proposed subbasins.

Technical Study and Subsurface Data (§ 344.14 (a)(2))

As part of the effort to evaluate the potential for dividing the Cuyama Valley Groundwater Basin into two subbasins, Cleath-Harris Geologist evaluated the sealing potential of the Russell/Whiterock fault zone. This evaluation included an examination mud and e-logs from oil wells drilled in the region, review of engineering reports for regional oil wells where available, lithologic/mud logs and e-logs from water wells when available, and a review of mapped surface geology. Regional water quality and water level data was also reviewed in an effort to characterize subsurface formations and structure.

The proposed scientific external boundary modification is based on a technical evaluation of fine-scale (1;24,000) geologic mapping which shows discontinuities in water-bearing sediments along the newly proposed basin boundary. This is further discussed below.

Demonstration of Hydrologic Barrier to Flow (§ 344.14 (b))

Overview

The proposed subdivision of the Cuyama Valley Groundwater Basin is based on a flow barrier created by the Russell fault zone. Several mechanisms are responsible for retarded flow through fault zones. Broadly, these break into two categories: juxtaposition and fault-related barriers (Knipe 1992). In juxtaposition, permeable beds are offset against impermeable beds, breaking the flow pathways. When this is not the case, the physical characteristics of the fault itself must impede flow. This can occur by means of several mechanisms. First, fault motion fractures rock, creating preferential flow paths (usually sub-vertical) which can rapidly cement through mineralization. This cementation reduces permeability in the horizontal direction, and is a mechanism that is more prevalent in lithified sediments. The second mechanism is through the formation of cataclastic material in the fault plane. Cataclastic material is finely ground rock (effectively rock dust or fault gouge) which has lower permeability than the surrounding material. Again, this mechanism is most prevalent in lithified formations. The final mechanism is clay smearing. In soft shales or unconsolidated sediments, the motion of the fault (particularly vertical motion) drags softer material (clay) along the fault zone as it moves. This ‘smeared’ clay creates a zone of reduced permeability that retards cross-fault flow. The percentage of clay, thickness of clay beds, and throw of fault (movement) all impact fault seal, with an increase in any of those factors resulting in a higher degree of retardation. (Bense et al. 2013). This clay smear mechanism is the dominate mechanism at work in unlithified, faulted sediments (Lehner and Pilaar 1997, Eichhubl et al. 2005, Rawling and Goodwin 2006).

Documentation in this section is intended to demonstrate firstly that sufficient offset exists for juxtaposition of aquifer units across the fault, and, secondly, that offset and stratigraphy are sufficient to create an additional permeability barrier. Bulletin 118 lists several evidences of a barrier including differential water levels, associated springs, and differential water quality. Each of these factors has been examined in evaluating the proposed Chalk Mountain Subbasin. Of these three evidences, historic springs associated with the fault, and water quality variations across the fault are present. The third evidence, differential water level, is inconclusive due to sparse distribution of data. However, along the river where the greatest concentration of wells exist, both differential water levels and differing water level trends can be observed (Figure 24).

Qualified Map of Geologic Structure Impeding Groundwater Flow Aquifer Extent (§ 344.14 (b)(1))

Figure 2 is a map showing the Russell fault as mapped by by Smith (1964) and Jennings and Strand (1969). This structure, as mapped here, is the barrier that is the basis for the proposed internal boundary. Figure 2 also shows the unnamed fault which provides the basis for the proposed external boundary modification.

Technical Study of geologic and hydrologic conditions along the proposed boundaries (§ 344.14 (b)(2))

Cleath-Harris Geologists (CHG) has conducted a technical study of geologic and hydrologic conditions along the proposed internal and external boundaries. As part of a review of external basin boundaries, this study evaluated local scale geologic mapping (1:24,000) previously conducted by Dibblee (various maps). This review found one zone which was discontinuous with the basin. Further work determined drainages within this zone entered the Cuyama River downstream of the basin, illustrating this zone is hydraulically isolated from the basin.

This study also evaluated the scientific data available in an effort to determine the impacts of the Russell fault system on intra-basin flow. This work included an evaluation of fault offset and the effects of juxtaposition on water-bearing sediments, and a characterization of fault properties with regard to flow. This effort serves to illustrate that geologic conditions exist to create a barrier to groundwater flow. Next, an evaluation of historic and active springs along the fault was conducted, and water quality and water level data was reviewed and evaluated to illustrate that this barrier has a measurable impact on both groundwater flow and quality. A more detailed discussion of these findings follows.

Other Information: Demonstration of Fault offset of Aquifer Units-External Boundary (§ 344.14 (b)(1)(E))

Basin definition has demarked the base of the water-bearing sediments as corresponding to the base of the Morales Formation. Examination of coarse-scale mapping of the basin (1:250,000) indicated that water bearing sediments extended in a northwestward finger from the Gifford Ranch (Figure 2). Mapping (Jennings 1958) also illustrates an unnamed fault which crosses these water bearing-sediments trending approximately north-south. The current Bulletin 118 boundaries are based on this coarse-scale mapping. Examination of finer-scale mapping (Dibblee, DF-262, DF-263 and DF-265) indicates that these water bearing sediments are not continuous. North of the unnamed fault (Figure 4), older nonwater-bearing sediments are faulted against the Morales Formation. While two additional zones of Morales Formation crop out north of this fault, they are separated by zones of nonwater-bearing sediments. These two zones represent Morales Formation that has been dragged and isolated along the La Panza fault. As faulting has juxtaposed water-bearing Morales Formation against non-water bearing sediments isolating these zones from the basin, areas north of the unnamed fault should be removed from the basin.

Other Information: Watersheds Relating To The External Boundary Modification (§ 344.14 (b)(1)(E))

Watersheds in the finger that would be removed from the basin were evaluated to examine the impact that truncating the basin would have on surface water. Figure 5 illustrates the relationship between drainages, the existing Bulletin 118 boundaries and the proposed external boundaries. Beginning just north of the proposed boundary, all drainages flow westward, eventually entering the Cuyama River downstream of the basin. Surface precipitation and runoff from this area does not flow into the main portion of the basin. Thus, not only is the bedrock in this finger structurally isolated from the basin, surface waters in the zone flow away from the basin. Without hydraulic connection, this zone should be removed from the basin.

<u>Other Information: Demonstration of Fault offset of Aquifer Units- Internal Boundary (§ 344.14 (b)(1)(E))</u>

In determining that the Russell/Whiterock fault systems provide a barrier to flow as required by Bulletin 118, CHG developed 10 cross-sections along the proposed sub-basin boundary (Figure 3). All of the cross-sections were based on active and historic well logs available through California Department of Oil, Gas and Geothermal Resources (DOGGR). Log data were generally unavailable for the top 100-300 feet of formation (generally fan deposits and older alluvium) but covered substantial portions of the water-bearing sediments (Figures 8-17). This zone generally contains deposits younger than the Morales Formation, including fan deposits, older alluvium and younger alluvium. All of these units are shown in surface geology maps of the region (Figures 3 and 6). Oil wells are abundant along the fault and explore traps created by various splays of this fault zone. Based on locations of both producing and exploratory oil wells, it is apparent that the zone of interested for the Russell fault extends considerably beyond the location mapped by Smith and Jennings, and likely extends a minimum of 3000 feet east of this mapped fault and at least 1000 feet west of the line. This corresponds with the zone in which faults have been mapped within the geologic literature for the area and is consistent with the complexity of the fault zone which has both translational (lateral) and compressional (thrust) movement.

Previous work by Nevins (1983) and Schwing (1984) developed deep structure across the evaluated zone. This work was focused on structure significant to oil exploration. However, the geologic structure was not well documented above the base of the Morales Formation. Both Nevins and Schwing state that deformation ceased at the time of the Morales Formation, but they also note that deformation exists within the Morales Formation. The deformation of the Morales Formation was characterized as minor, but Nevins and Schwing noted that it had not been fully evaluated. Subsequent studies also failed to fully evaluate deformation within the Morales Formation. To test this assumption of limited deformation, key marker beds identified by these authors were located and identified in all section lines developed by CHG. Additional studies were completed by the USGS to identify key horizons within the Morales Formation. These markers were identified in the central portion of the Cuyama Valley Groundwater basin (Sweetkind et al. 2013) which lies to the east of the zone under evaluation. These include marker beds G1, G2, G3, and the top and base of the Quatal Formation. Each of the marker beds associated with this horizon were located and identified in all lines developed by CHG.

Evaluation of Morales Formation marker beds (G1, G2, and G3) and structure strongly suggests that the Russell fault has offset associated with loss of accommodation space in the basin (onset of compression along the Whiterock and South Cuyama thrust faults). To illustrate this, each horizon on each cross-section was evaluated to determine apparent offset. A summary of these evaluations is included in Table 1 below. Offsets are generally highest in the north and south of the proposed boundary line (nearest the Whiterock and Cuyama Thrust faults, respectively). Faults in the far north (Lines A, B, C) show significant thrusting which offset sediments to the extent that no contact of water-bearing units across the fault exists. The middle portion of the subbasin boundary (Russell Fault zone) (Lines D, E, F and G) showed less offset (generally 100-200 feet) but has greater influence from adjacent faults like the Turkey Trap Ridge fault. Faults near the south of the proposed boundary show offsets of 200-800 feet, indicating the Russell fault system accommodated significant motion in this area.

Marker Bed Offset Across Russell/White Rock Fault (Feet)							
	Marker Bed						
Line	G1	G2	G3	USGS Morales	USGS Quatal	Nevins Morales	Nevin Branch Canyon
A-A'	>500	>500	>500	>500	>500	>500	>500
B-B'	>500	>500	>500	>500	>500	>500	>500
C-C'	>500	>500	>500	>500	>500	>500	>500
D-D'	ND	ND	400	300	250	250	220
E-E'	ND	ND	140	120	120	115	ND
F-F'	ND	ND	125	190	190	175	220
G-G'	180	170	160	100	100	140	300
H-H'	250	250	240	300	305	315	250
I-I'	800	650	800	830	850	ND	ND

Table 1: Apparent offset across the Russell/White Rock Faults

Cross-sections illustrate offset through the majority of the Morales Formation, and surface mapping (Dibblee 2005) shows fault traces in surface-exposed outcrops of the Morales Formation. However, based on cross section data, there is no evidence offset of in the more recently deposited fan materials, and older and younger alluvium.

An evaluation of literature on this area indicates that early mapping cross-sections (Eaton 1939) show the Russell fault bisecting the younger terrace materials. More recently, evaluation of the older and younger alluvium deposits of the Cuyama Valley was conducted by DeLong et al in 2007. Delong notes that the Q2 and Q3 terrace deposits show evidence of disruption by thrusting along the Whiterock fault. This would place the end of compressional displacement between 45,000 years (Q3 age) and 30,000 years (Q4 age) before present. As the Russell fault accommodated a degree of basin contraction, this would likely mark the end of movement along the zone. Delong's terrace map shows up-thrust bedrock near the juncture of Whiterock and

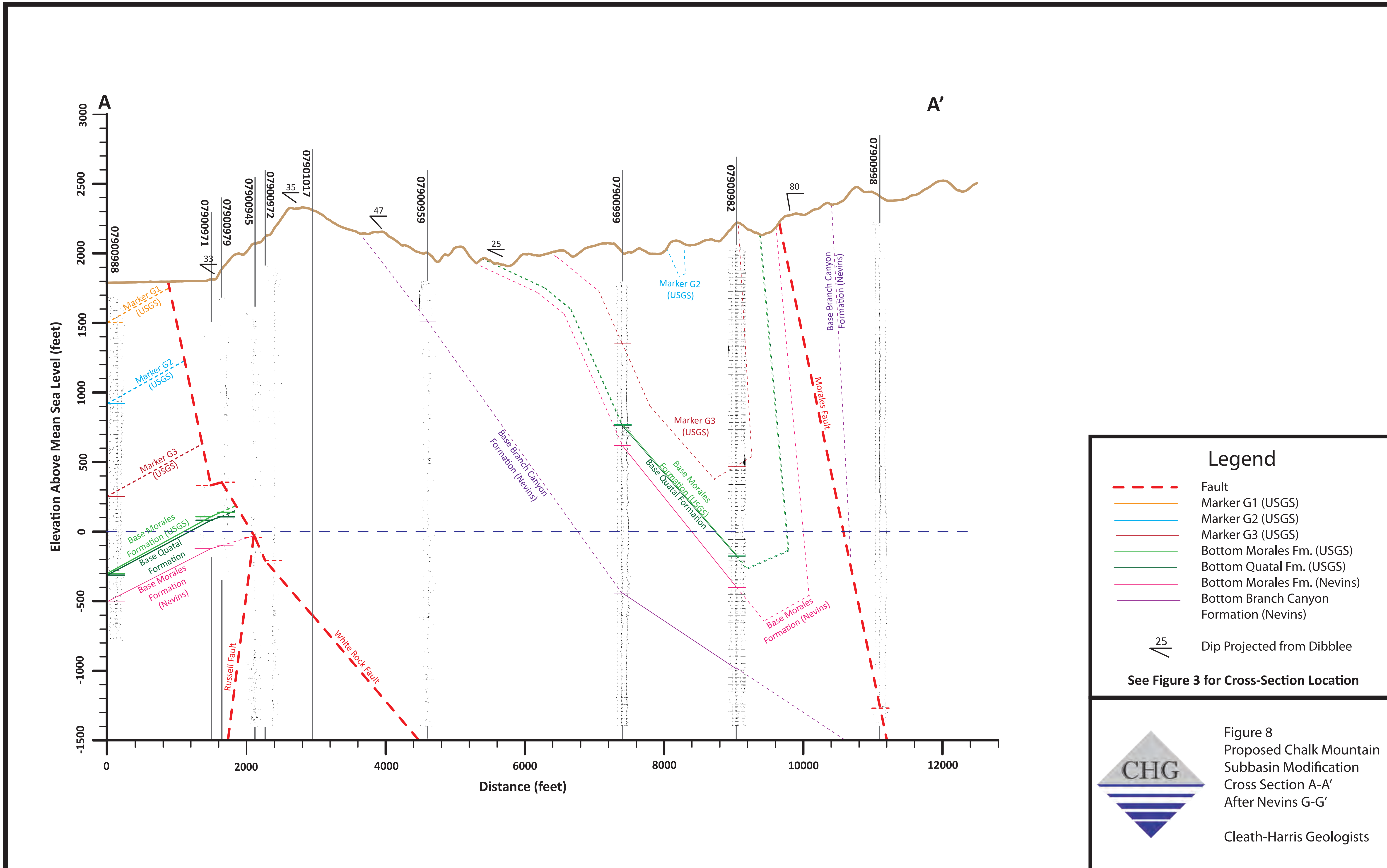
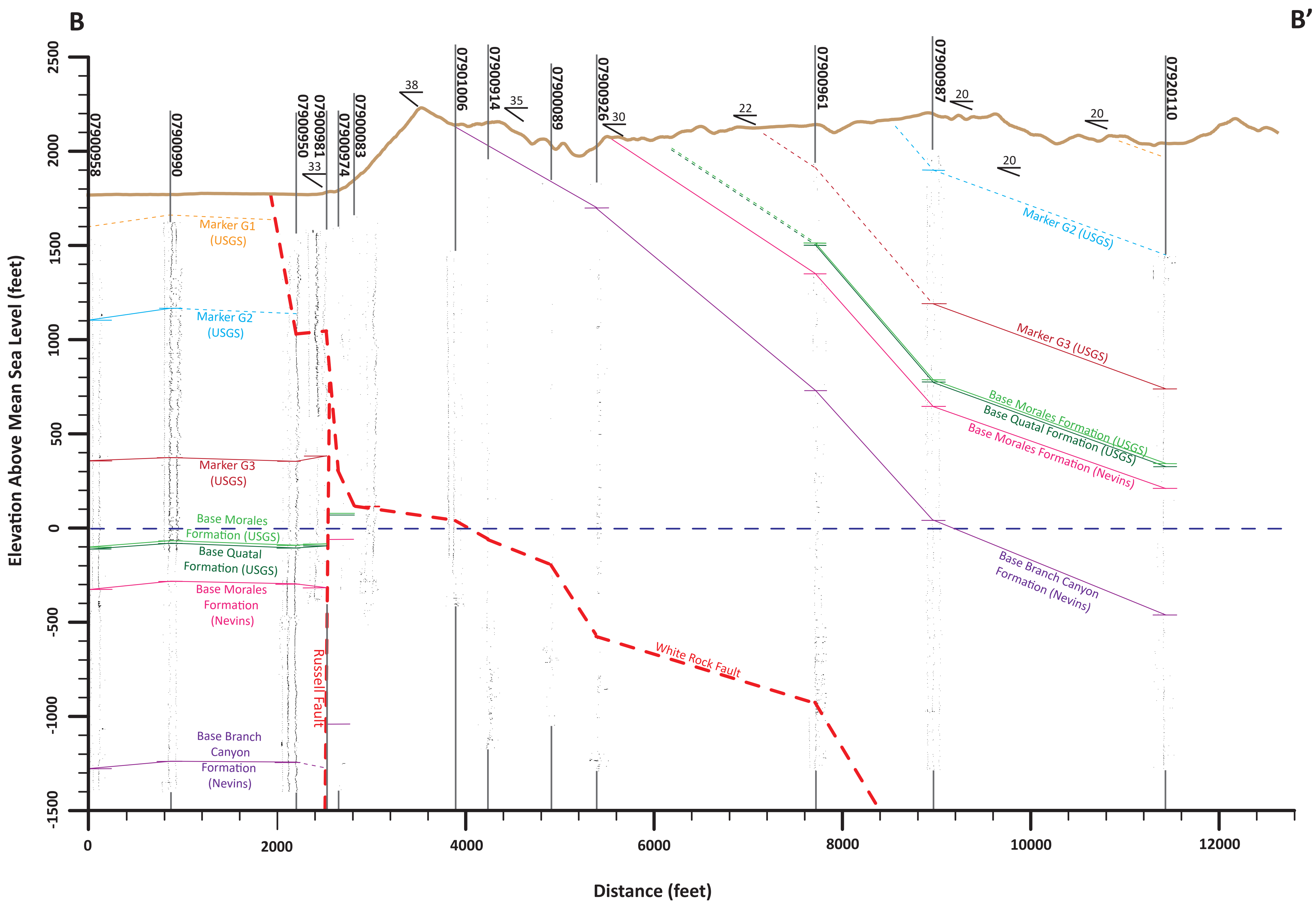


Figure 8
Proposed Chalk Mountain Subbasin Modification
Cross Section A-A'
After Nevins G-G'

Cleath-Harris Geologists



Legend

- Fault
- Marker G1 (USGS)
- Marker G2 (USGS)
- Marker G3 (USGS)
- Bottom Morales Fm. (USGS)
- Bottom Quatal Fm. (USGS)
- Bottom Morales Fm. (Nevins)
- Bottom Branch Canyon Formation (Nevins)
- 25 Dip Projected from Dibblee

See Figure 3 for Cross-Section Location

Figure 9
Proposed Chalk Mountain Subbasin Modification
Cross Section B-B’
After Nevins F-F’

Cleath-Harris Geologists

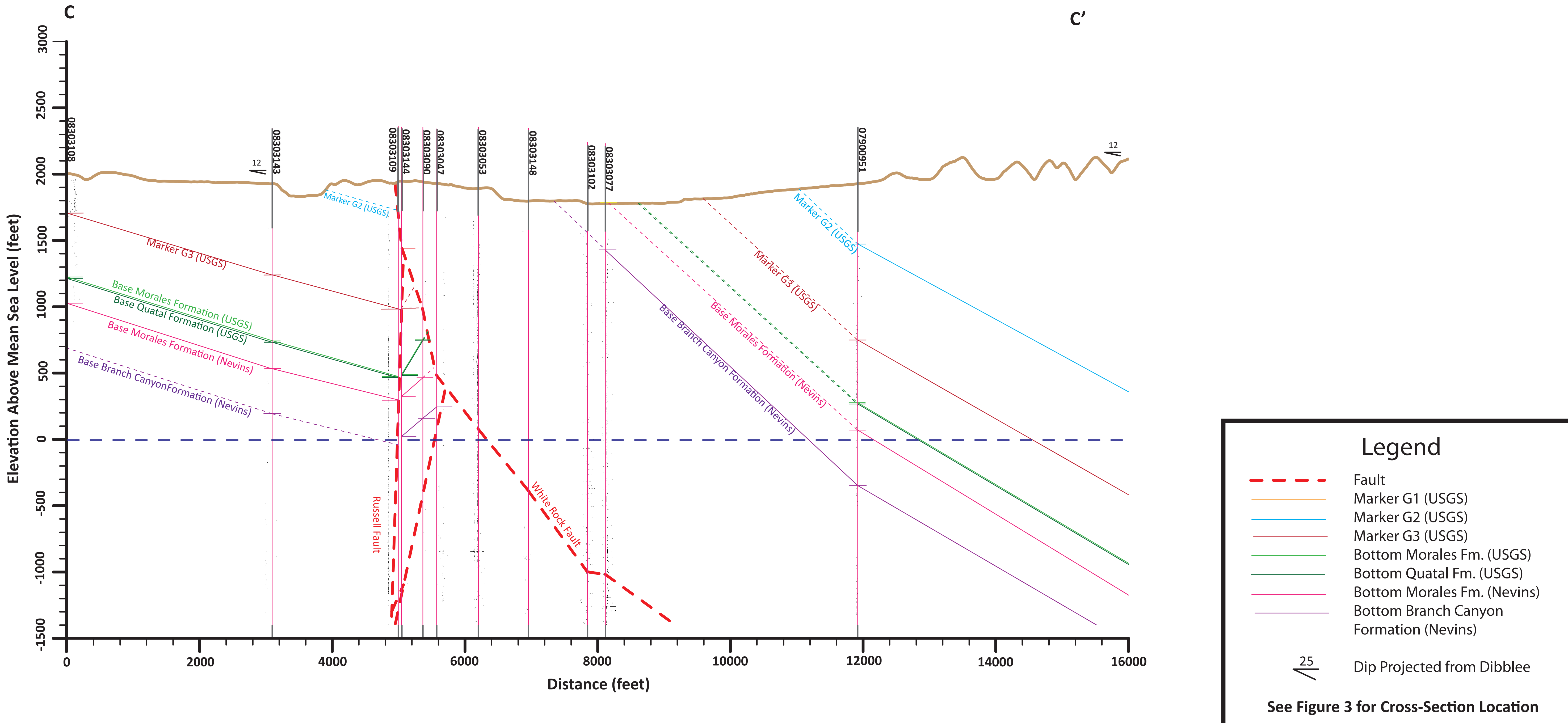


Figure 10
Proposed Chalk Mountain Subbasin Modification
Cross Section C-C'
After Nevins E-E

Cleath-Harris Geologists

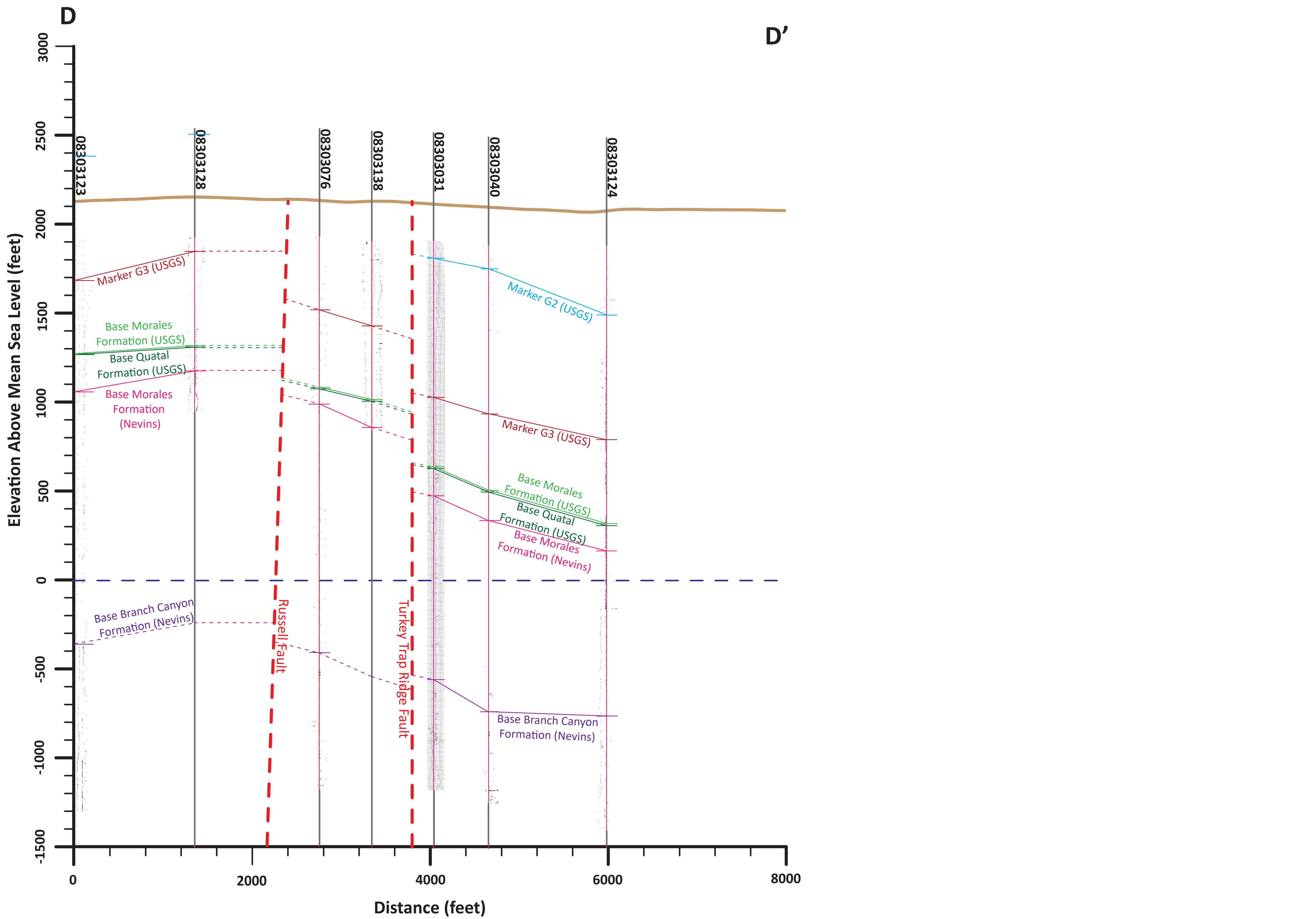
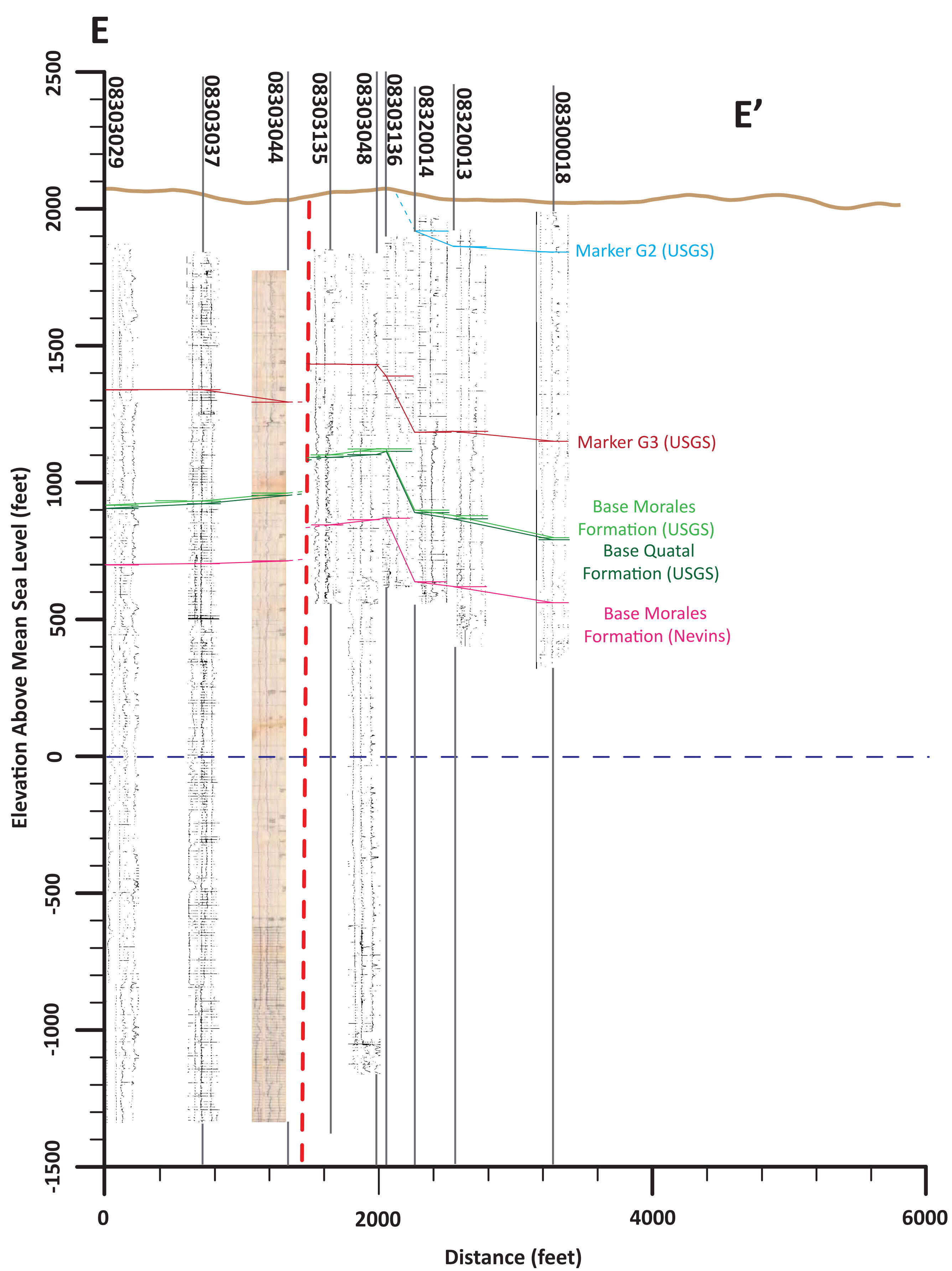


Figure 11
Proposed Chalk Mountain Subbasin Modification
Cross Section D-D’
After Nevins D-D’

Cleath-Harris Geologists



Legend

Fault
Marker G1 (USGS)
Marker G2 (USGS)
Marker G3 (USGS)
Bottom Morales Fm. (USGS)
Bottom Qatal Fm. (USGS)
Bottom Morales Fm. (Nevins)
Bottom Branch Canyon Formation (Nevins)
25 Dip Projected from Dibblee

See Figure 3 for Cross-Section Location

CHG

Figure 12
Proposed Chalk Mountain Subbasin Modification
Cross Section E-E’
After Nevins C-C’

Cleath-Harris Geologists

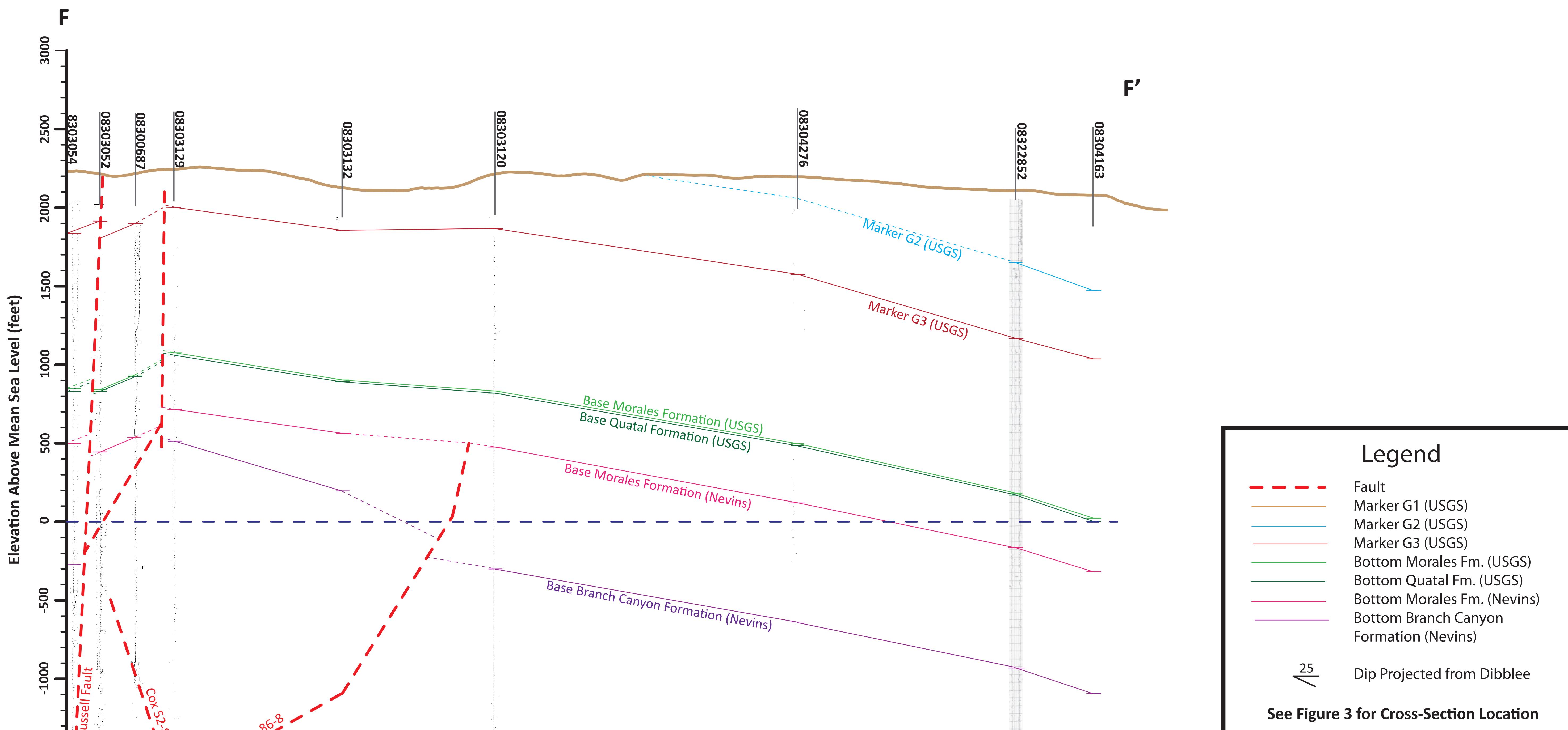


Figure 13
Proposed Chalk Mountain Subbasin Modification
Cross Section F-F’
After Nevins B-B’

Cleath-Harris Geologists

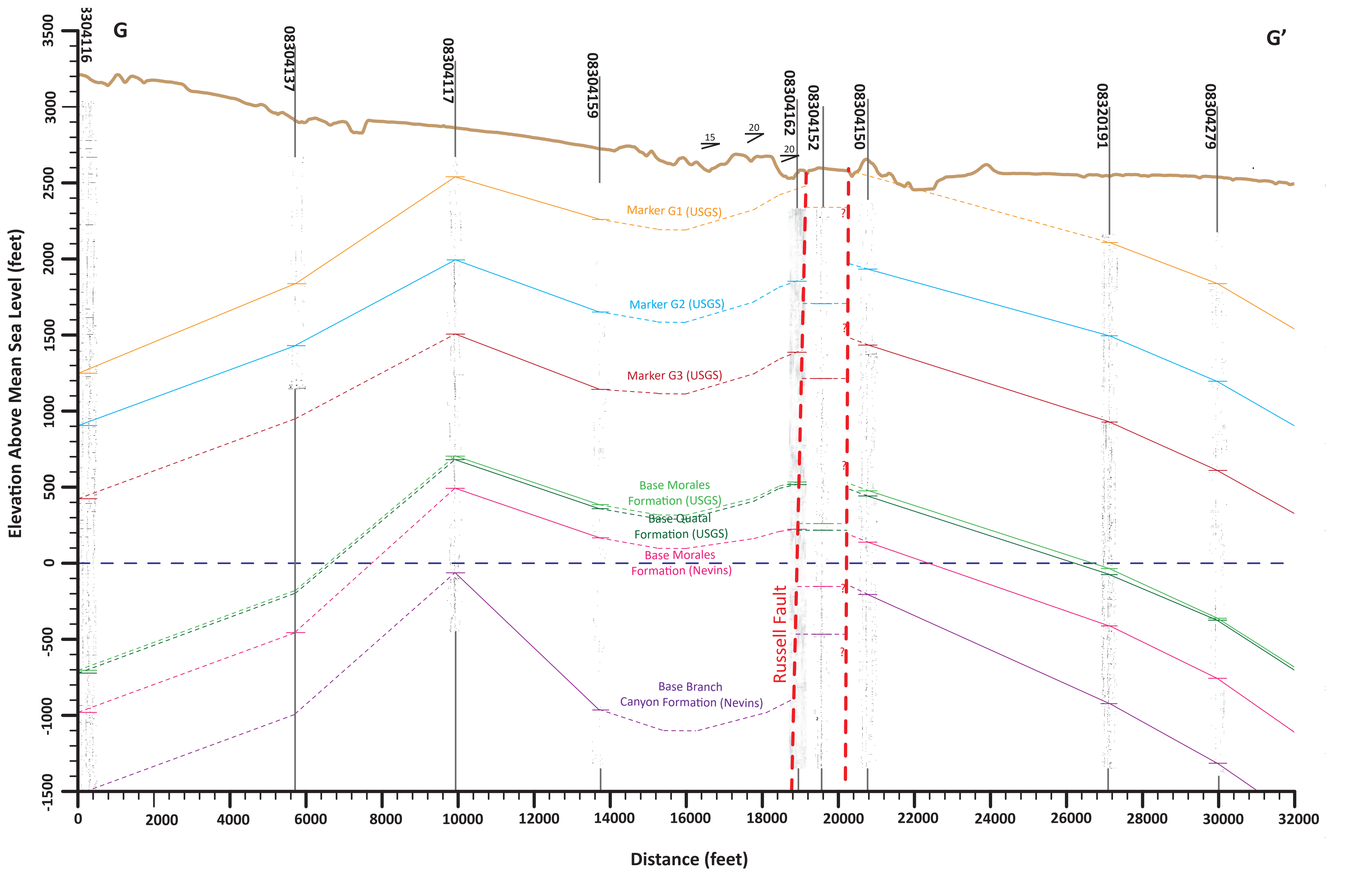


Figure 14
Proposed Chalk Mountain Subbasin Modification
Cross Section G-G'

Cleath-Harris Geologists

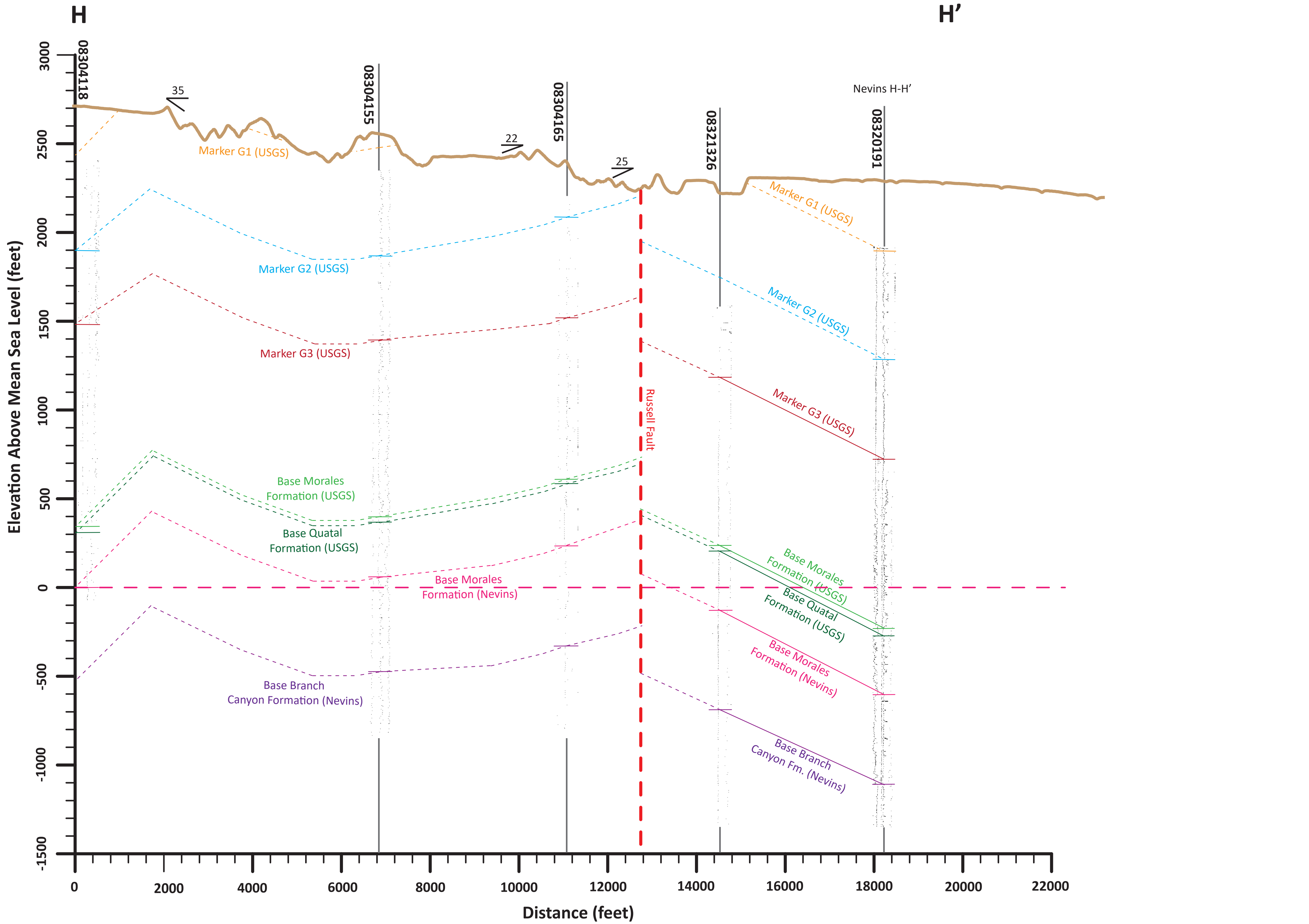


Figure 15
Proposed Chalk Mountain Subbasin Modification
Cross Section H-H'

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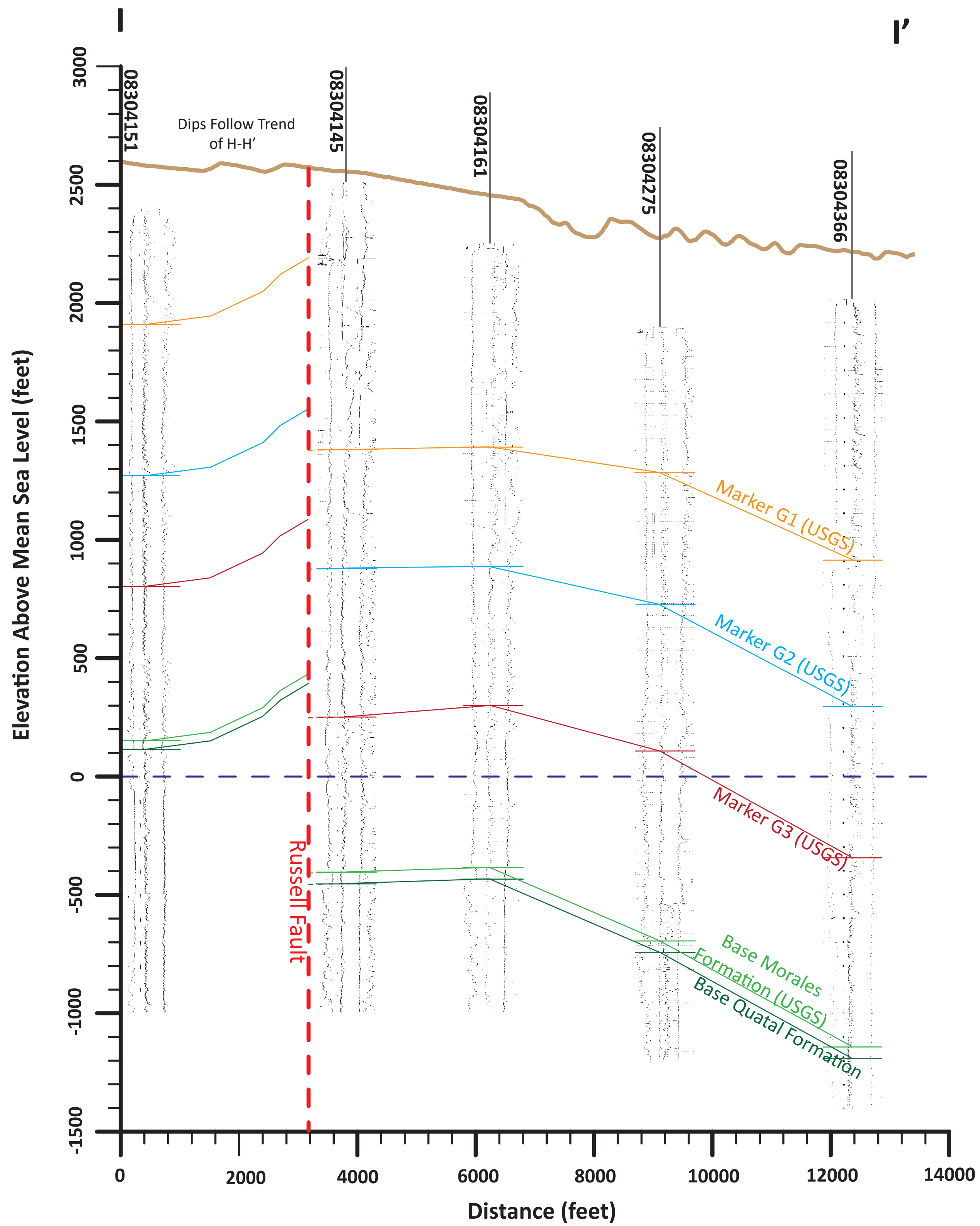

Legend

- Fault
- Marker G1 (USGS)
- Marker G2 (USGS)
- Marker G3 (USGS)
- Bottom Morales Fm. (USGS)
- Bottom Quatal Fm. (USGS)
- Bottom Morales Fm. (Nevins)
- Bottom Branch Canyon Formation (Nevins)
- 25 Dip Projected from Dibblee

See Figure 3 for Cross-Section Location

Figure 16
Proposed Chalk Mountain Subbasin Modification
Cross Section I-I'

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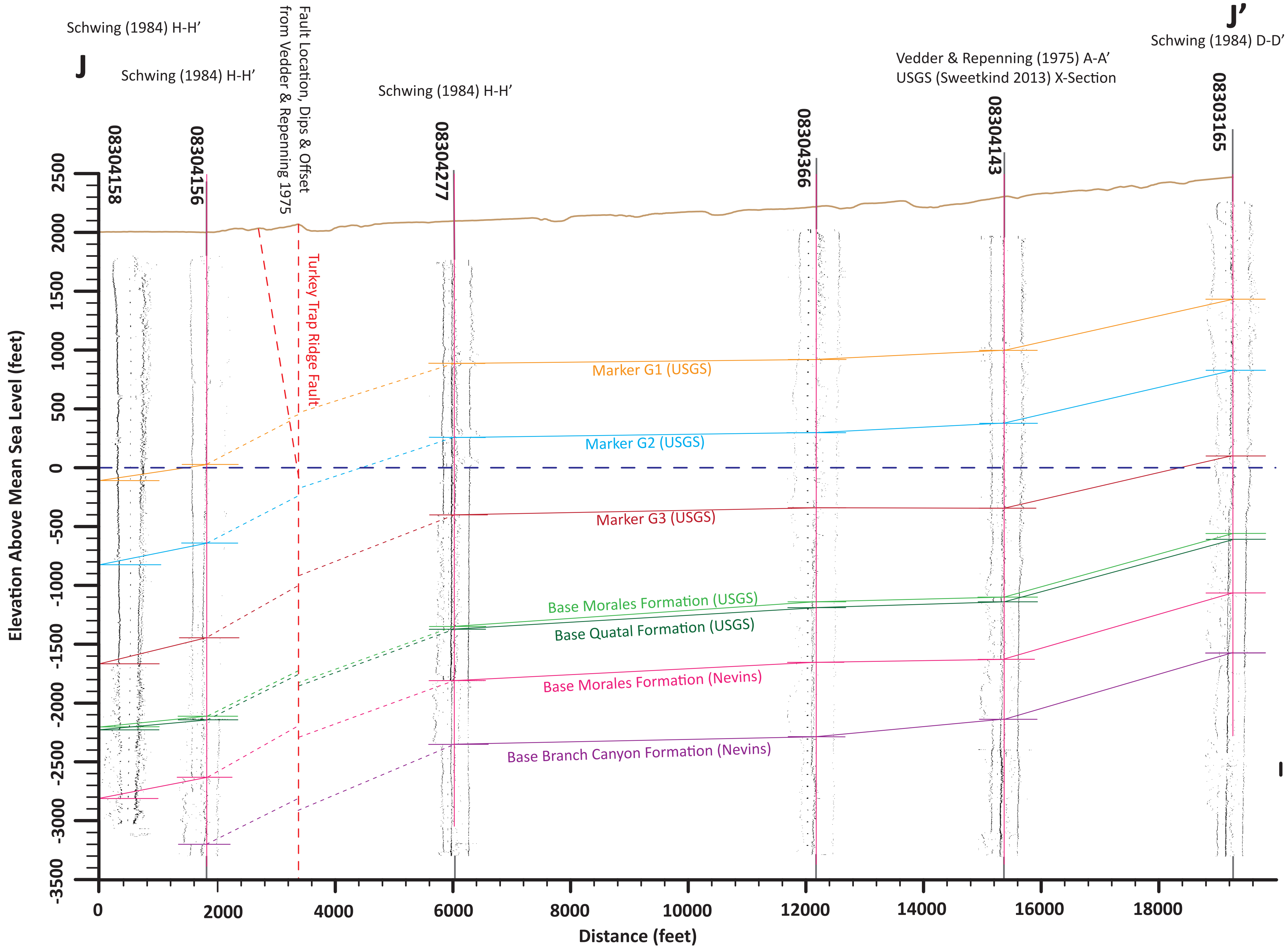


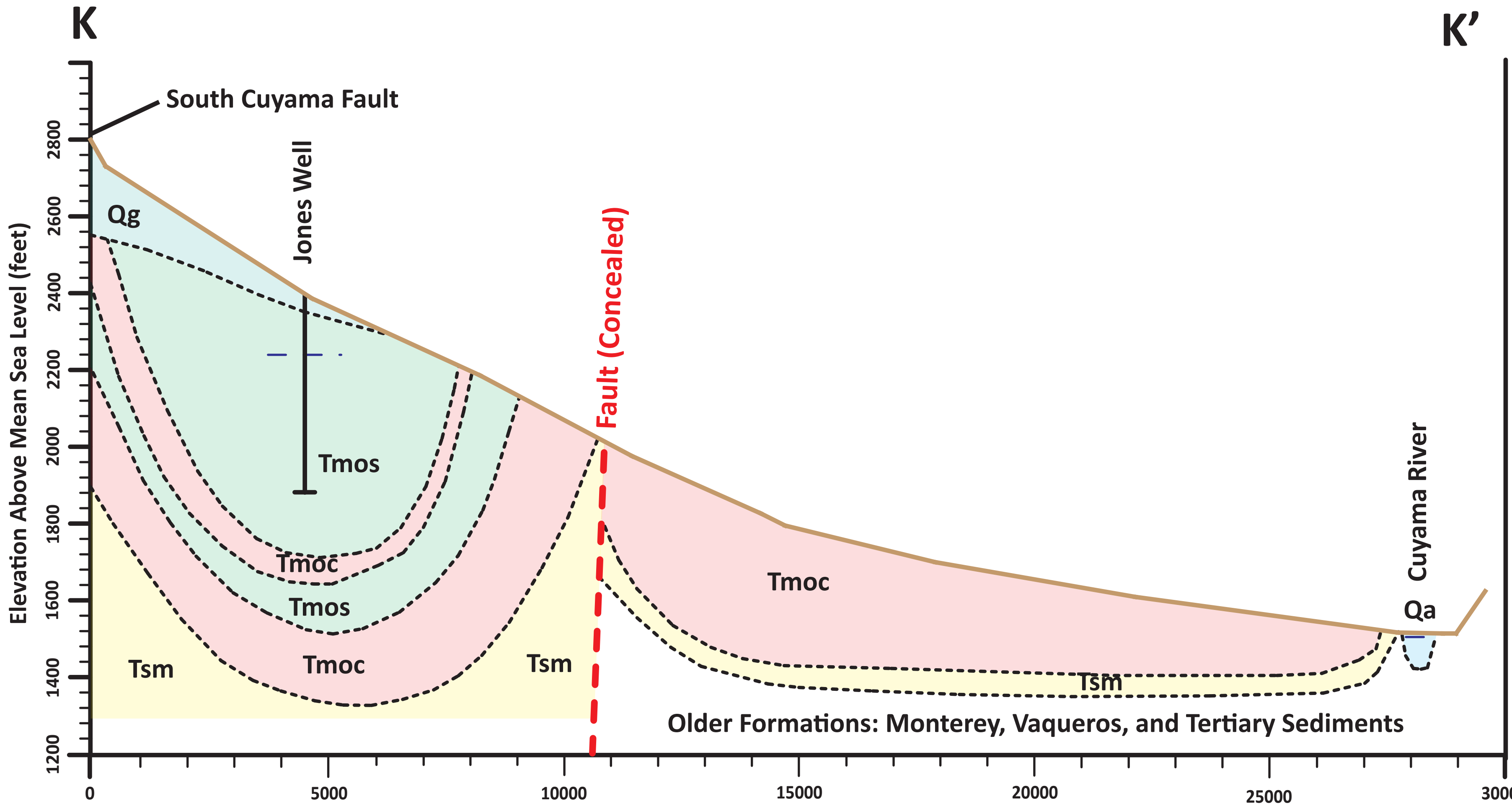
Legend

See Figure 3 for Cross-Section Location

CHG

Figure 17
Proposed Chalk Mountain Subbasin Modification
Cross Section J-J'
After Schwing 1984, Vedder andRepenning 1975

Cleath-Harris Geologists



Explanation

Qa: alluvium
Qg: fan gravels
Tmos: Morales- sands and clays
Tmoc: Morales- clays
Tsm: Santa Margarita Sandstone
water level (2017)

CHG

Figure 18
Proposed Chalk Mountain Subbasin Modification
Cross Section K-K'
Geology of Cottonwood Canyon

Cleath-Harris Geologists

Turkey Trap Faults, as well as a number of lineations and notches where the terrace material is disrupted by these faults. Examining the trace of the Russell fault shows similar disruptions including lineations, abrupt departures in stream direction and notched transitions between terrace deposits. This suggests terrace material (and the immediately underlying Morales Formation) has been disrupted by the Russell fault similar to what is observed along the Whiterock fault system. This would bring the fault barrier to at, or very near, the surface and above regional water levels (Figures 23 and 24). Only the alluvial material along the Cuyama River Channel remains both undisturbed and in hydraulic contact across the proposed subbasin boundary.

Other information: Fault Seal Analysis (§ 344.14 (b)(1)(E))

Quantitative evaluation of the barrier behavior with sparse data (no or limited well testing data) has been a focus of research for the oil and gas industry for many years. Several methods have been developed in the industry including Shale Gouge Ratio (SGR) analysis and Shale Smear Factor (SSF) analysis, which are more fully discussed below. For oil and gas, trapping is accomplished both through permeability reduction and through the increased capillary entry pressure that entrained clays in the fault zone create. Analysis methods directly gauge the permeability effects of faulting and, based on significant field data, correlations have been determined for capillary effects (Bretan et al. 2003). In hydrogeologic systems, single phase flow abrogates the need to evaluate capillary effects within fault material. However, the method can (and has) been utilized to evaluate faulting effects on fluid flow within groundwater systems (Bense and Van Balen 2004). Ideally, multiple points along a fault zone should be evaluated, but experience within the oil industry has shown that even single point (well) evaluations within the zone of interest can provide valuable insight into fault behavior in the absence of more comprehensive data.

All major methods of evaluating the quality of fault seal require several key pieces of information. These include lithology for sediments along the fault within reservoirs (aquifers) of interest, displacement of the fault zone in areas to be evaluated, and expected differential pressure across the fault zone. Increases in fault throw, and higher clay content improve seal quality. Increases in pressure require either a thicker fault zone, or lower permeability to maintain a given flux rate under Darcy's Law.

Using cross sections developed to evaluate offset across the fault, throws across multiple fault positions was determined (Table 1). For purposes of analysis, the smallest encountered throw of 100 feet and a more typical throw of 200 feet were used. The 100-foot throw represents the lowest sealing potential for offset in the system. Water level data is sparse adjacent to the fault (see discussion that follows), however, based on available data, water level change across the fault is not more than 100 feet (less the 50 psi pressure differential), and is likely much less than this.

Wells along the fault were examined to find available lithologic and e-logs. As oil wells typically neglect near-surface sediments in both e-logs and lithologic logs, data from a water well, North Forks Well #4 (Figure 3), was used to evaluate clay within the water-bearing zones of the Morales Formation. A summary of this log is available in Figures 19-22. This well lies adjacent to the fault zone, and for purposes of analysis, is assumed to be representative of typical water-bearing Morales Formation along the fault. Based on geologic mapping work conducted by Dibblee, the Morales Formation is adjacent to the entire west side of the Russell fault zone (veneered with a thin layer of fan deposits which generally lie above the water table). This data provided the basis for the SGR and SSF analysis that follows. As part of the analysis, clay content was assigned to each of the lithologies described in the lithologic logs. Assigned clay percentages are based on lithologic log notes, and published literature (Bense and Van Balen 2004). These are summarized in Table 2.

Lithology	% Clay
Sand and Gravel	0
Sand	0
Sand, Fine	10
Clayey Sand with Gravel	30
Sandy Clay with Gravel	45
Clayey Sand	30
Clay with Sand	65
Sandy Clay	65
Clay	85

Table 2: Clay ratio assigned to lithologic units

Shale Smear Factor Analysis

The shale smear factor (SSF) method of analysis was developed in the early 1990's (Lindsey et al. 1993) to help quantitatively assess the degree of continuity of sealing clays along a fault. This method assesses the likelihood that the entrained clay layer is continuous within the fault zone. Under this method the SSF number is calculated using the following formula:

SSF= Fault Throw/Sum of Shale Layer Thicknesses

Fault throw is evaluated in feet, and shale layer thicknesses are evaluated in segments for the fault that are typically equivalent to the fault throw. Under this method, lower SSF values have a higher likelihood of continuous clay smear. Based on fault evaluations in multiple localities it has been found that SSF factors of less than 3 have a high likelihood of being continuous across the fault plane. Factor values from 3-10 are increasing less likely to be continuous (moderately continuous), and factor values greater than 10 are considered non-continuous (Lindsey 1993, Bense 2013). Continuous clays within the fault zone are key to providing a permeability barrier that would demonstrate impeded flow. SSF analysis was conducted assuming both a 100 foot and 200 foot throw. Figures 19 and 20 illustrate the results of this analysis.

In both sets of analyses, data was unavailable for the first 90 feet of formation and results within this zone are unavailable. Within the analysis for the minimum throw of 100 feet, all zones

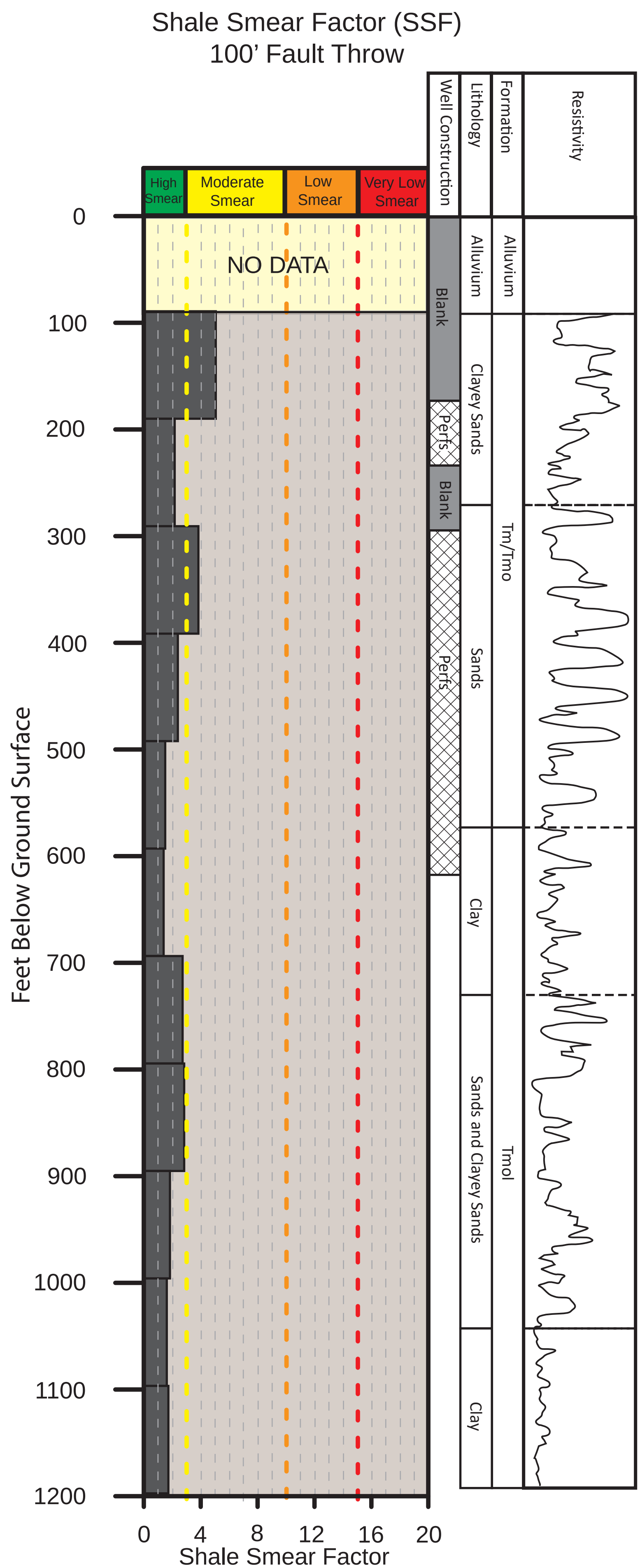


Figure 19
Shale Smear Factor (SSF) Analysis
North Forks #4/Russell Fault
Proposed Chalk Mountain Subbasin
Boundary Modification

Cleath-Harris Geologists

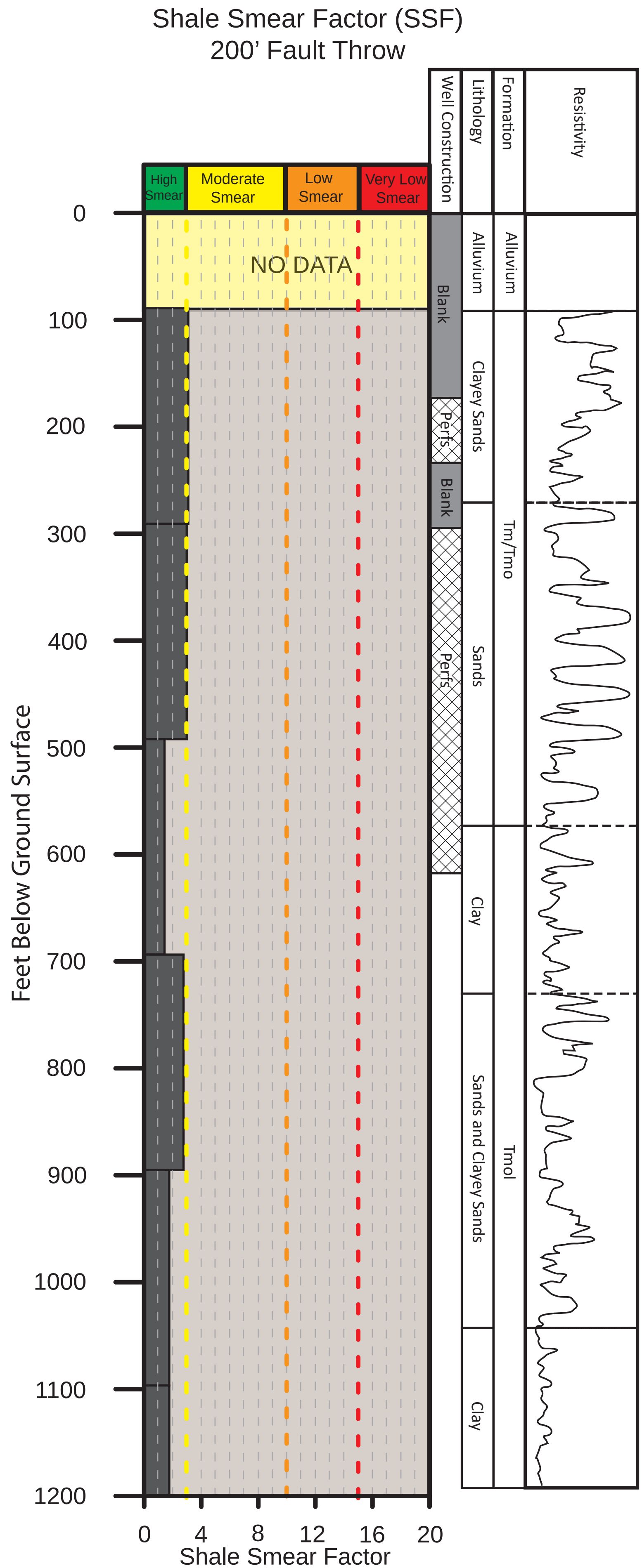


Figure 20
Shale Smear Factor (SSF) Analysis
North Forks #4/Russell Fault
Proposed Chalk Mountain Subbasin
Boundary Modification

Cleath-Harris Geologists

showed a high to moderate likelihood of continuous clay entrainment along the fault zone, with depths below 200 feet all having high likelihood of a good seal. In the 200-foot throw analysis, all zones below 100 feet had SSF values less than 3 and the zone from 90-100 feet was only slightly above the SSF threshold value of 3. In both cases SSF analysis indicates that the Russell fault zone has entrained clay across the entire water-bearing thickness sufficient to create a barrier to groundwater flow.

Shale Gouge Ratio Analysis

A second method to analyze fault seal is called the Shale Gouge Ratio. This method was developed to provide a better understanding of the pressure differential that could be supported the fault seal. The formula for establishing this ratio is:

SGR= Sum of Shale Layer Thicknesses/Fault Throw

This formula is the inverse of the previous SSF analysis, with the key difference being that the shale layer thickness can be conducted on a much smaller scale. If data is available for both sides of the fault, then this analysis can be evaluated on the scale of single beds. Given data for one side of the fault, the analysis should be conducted for larger blocks on the scale of material moving past a node point (throw) (Yielding and Needham 1998). For purposes of this analysis, shale layers were summed for the full throw thickness.

Within the oil industry, SGR values of 15-20% represent the boundary between non-sealing and sealing behavior for faults (Fristad et al. 1997, Yielding et al. 1997, Ellevset et al. 1998, Manzocchi et al. 1999, Yielding et al 2002). Field studies have determined that a SGR ratio of 15% will create sealing conditions with a pressure differential of up to 8 psi, and a SGR ratio of 18% will hold a cross-fault pressure differntial of 116 psi (Freeman et al. 1998). As SGR values increase above this range, the quality of the seal improves. For purposes of this evaluation, a value of 18% was used at a cutoff value as it represents more than twice the anticipated cross fault pressure regime. The results of this analysis are shown in Figures 21 and 22 and illustrate that for all evaluated zone (including aquifers) formation characteristics would lead to a sealing fault (barrier to flow).

Again, fault zone analysis was conducted from 90 feet below ground surface to 1,210 feet. At all evaluated depths and for both the minimum and typical throw of the Russell fault, the SGR values indicate that the fault will support a pressure of more than 110 psi (greater than twice the anticipated cross-fault pressure). A minimum throw analysis was also conducted and this indicated that under both the SSF and SGR methods, only 20 feet of throw were needed to create a seal along the fault.

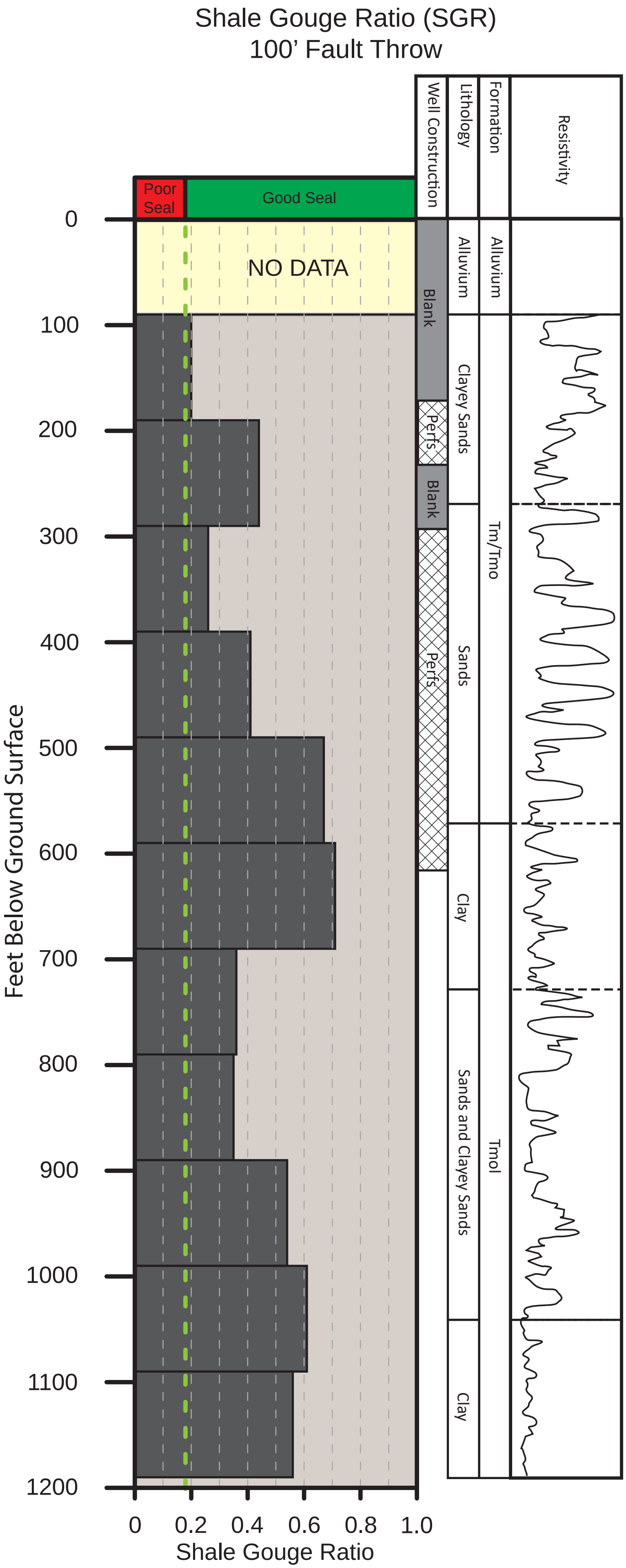


Figure 21
Shale Gouge Ratio (SGR) Analysis
North Forks #4/Russell Fault
Proposed Chalk Mountain Subbasin
Boundary Modification

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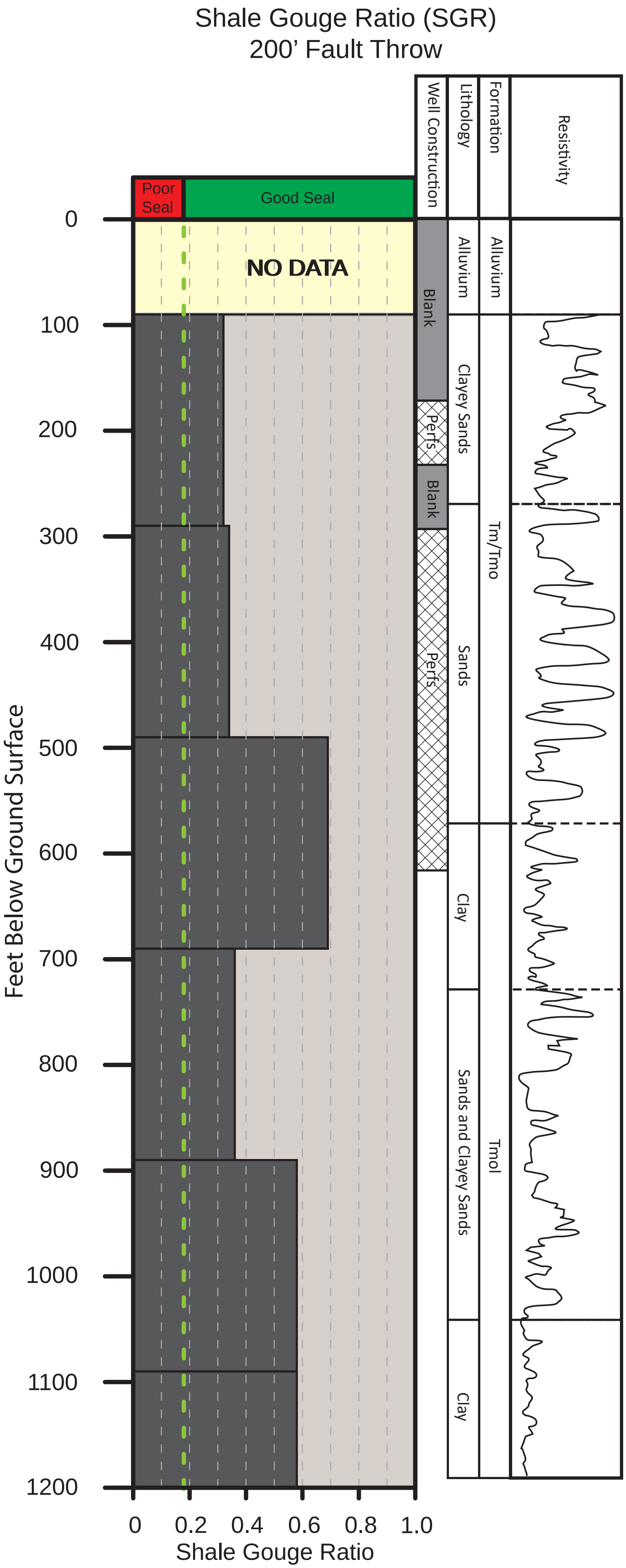

Figure 22
Shale Gouge Ratio (SGR) Analysis
North Forks #4/Russell Fault
Proposed Chalk Mountain Subbasin
Boundary Modification

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Spring and Historic Spring Discharge Along the Fault ((§ 344.14 (b)(1)(A))

Springs have been noted in conjunction with other internal fault barriers in the basin including the Graveyard NE1 and 2 Seeps, and Weir Springs, which are associated with the Graveyard Ridge fault. Additionally, Turkey Trap Springs Headquarters Springs #1 and #2, the Cuyama Ranch Hi-way Spring, No Name Spring, and Caltrans Station Spring are all associated with the Turkey Trap Ridge fault (Upson and Worts 1951, Singer and Swarzenski 1970, Vedder and Reppening 1975, Hanson et al. 2015). Several of these spring have seen either reduced flow or the cessation of flow with groundwater declines in the Graveyard Ridge area. The location of these springs is illustrated in Figures 3 and 6.

Two additional springs lie adjacent to the Russell Fault. Russell Spring and Caliente Spring lie south of Whiterock and Turkey Trap Ridge faults (Upson and Worts 1951, Hanson et al. 2015). These springs correspond to bedrock highs noted by Dibblee, Upson and Worts, Singer and Swarzenski. Extensive palustrine deposits exist west of the fault (DeLong et al. 2007) and correspond to the location of portions of the Russell Spring. Location and groundwater elevations indicate that water is rising along a fault barrier and flowing as springs.

Historic water level maps ((§ 344.14 (b)(1)(A))

A map of water levels from 1966 (the year of the most extensive regional measurements) is included as Figure 23. Records west of the fault are limited and no long term data exists west of the fault. One well recently drilled (2013) in the Ruby Star syncline showed artesian flow (Orange Well, Figure 24), suggesting bedrock units in this zone had not been depleted prior to this time. Since monitoring began in 2015, these wells have shown increases in water levels after pumping (Figure 24). This is contrasted to the Cuyama Valley Subbasin, which has been shown to be in critical overdraft (DWR 1980, DWR 2003, DWR 2017). Figure 24 more clearly illustrates this trend across the fault.

Water Quality information (§ 344.14 (b)(1)(C))

Water quality analysis conducted by the USGS during the period of 1953-1966 was examined and plotted both areally and in Piper Diagram to determine regional water quality trends across the fault zone. Water quality samples collected during this period represent the most regionally extensive, time equivalent series available. Additionally, water quality samples from this era predate water quality declines associated with cycling and evaporation of irrigation water (SBCWA 1996 and 2001).

Wells were divided into six groups based on location and source. Group 1 consists of shallow alluvial wells in the Sierra Madre foothills in the proposed Chalk Mountain Subbasin. Group 2 contains deeper, bedrock wells within this same zone. Group 3 wells are located in the alluvium

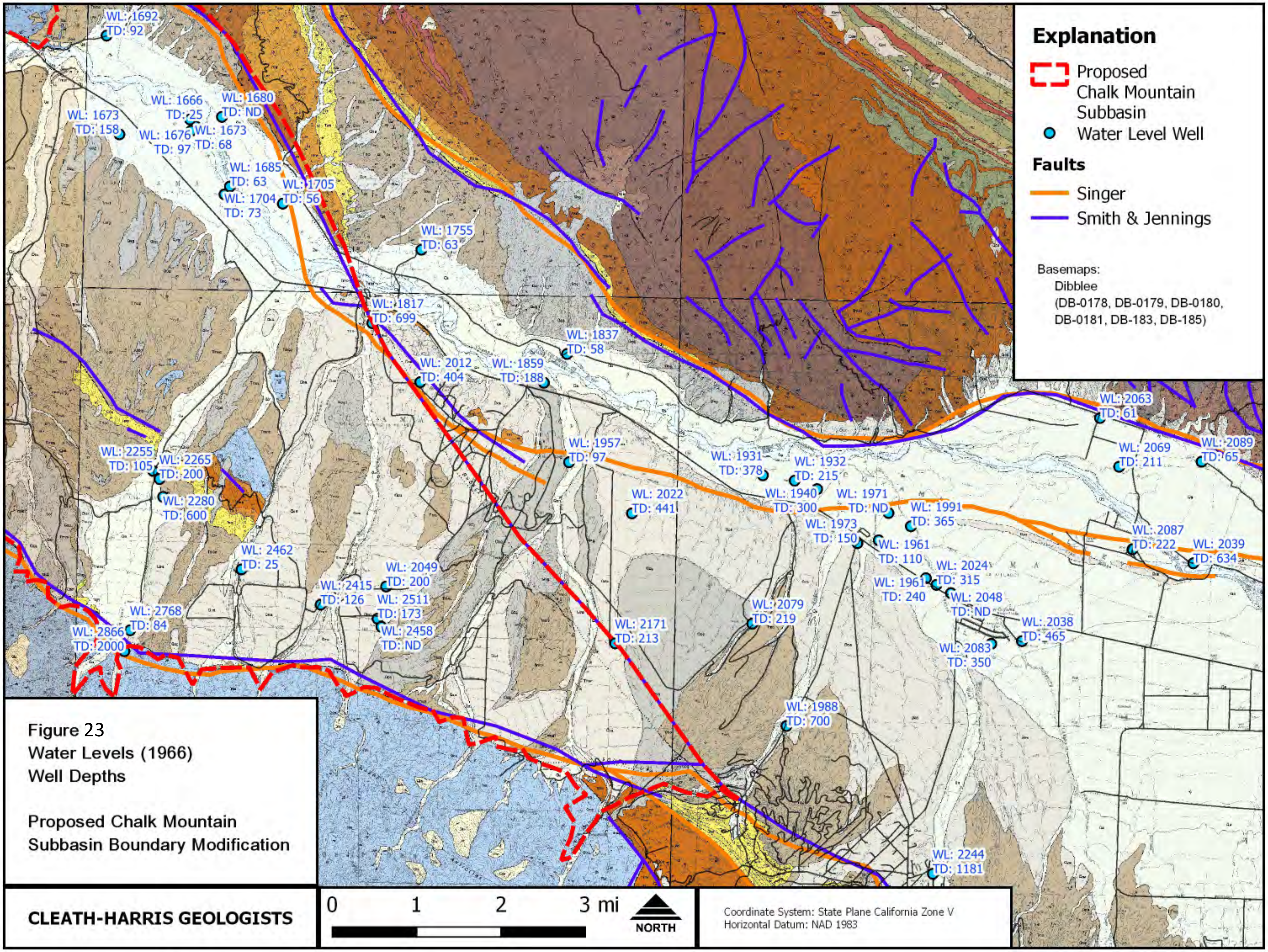

Figure 23
Water Levels (1966)
Well Depths

Proposed Chalk Mountain Subbasin Boundary Modification

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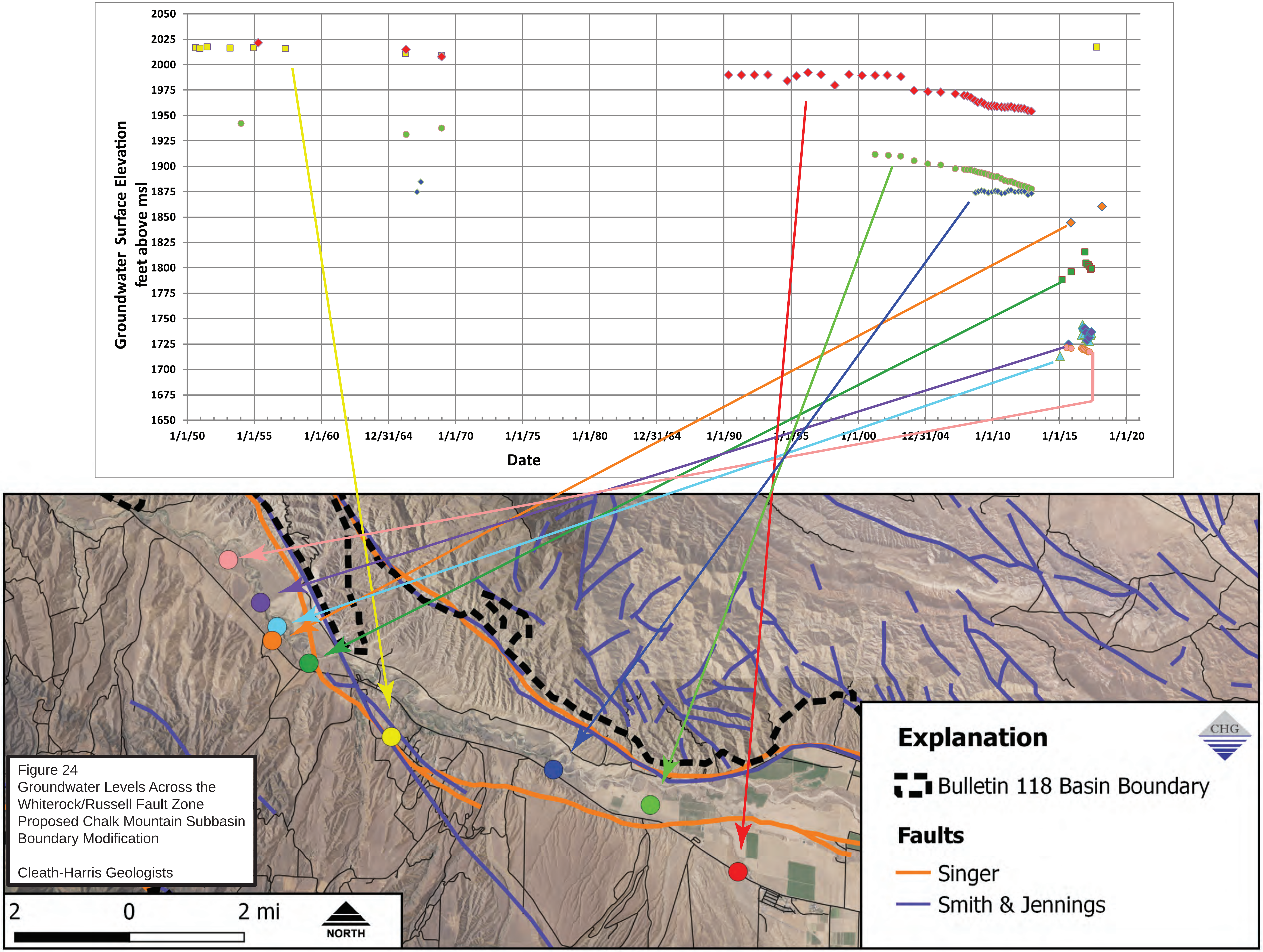

Figure 24
Groundwater Levels Across the Whiterock/Russell Fault Zone
Proposed Chalk Mountain Subbasin Boundary Modification

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and older alluvium material of the Cuyama River. Several these wells may slightly penetrate the upper portion of the Morales Formation. Group 4 covers the same areal extent but are deeper Morales Formation wells drilled since 2013 on the North Forks Ranch. Groups 5 and 6 lie east of the Russell fault, in the main Cuyama Valley Groundwater Basin. Group 5 lies between the Turkey Trap Ridge fault and the Sierra Madre Mountains and corresponds to the USGS grouping 'Northwest Sierra Madre Foothills' (Hanson et al. 2015). Group 6 lies along the river and is approximately equivalent to the USGS 'Western Basin' grouping (Hanson et al. 2015). An examination of water quality shows three principal sources of recharge, a high TDS saline source associated with the Cuyama River, a higher salinity source emanating from the Caliente Mountains and, lastly, a low TDS source associated with the Sierra Madre Mountains. The two high salinity sources highly influence Group 6 samples and the low salinity source most strongly influences water quality for wells in Groups 1 and 2. All other groups are effectively blends of these three source waters. This finding is consistent with previous studies (Upson and Worts 1951, Singer and Swarzenski 1970, Everett et al. 2013). Current water quality in Group 5 shows increased salt loading from agricultural cycling of groundwater (SBCWA 1994, SBCWA 1995, SBCWA 2001). A further discussion of the hydro-geochemistry of each group follows.

Group 1

Group 1 wells are shallow alluvial wells in major drainages emanating from the Sierra Madre Mountains west of the Russell fault. Wells in this group have TDS in the range of 500-600 mg/l. Water from this group is dominated by bicarbonate and chloride anions with mixed calcium-magnesium-sodium cations (Figure 26). TDS values are on the order of 1,000 mg/l lower than samples east of the fault and this zone shows. These values are in sharp contrast to samples east of the Russell fault.

Group 2

Group 2 wells lie west of the Russell Fault and have their recharge source in the Sierra Madre Mountains. These wells show TDS below 500 mg/l (Figure 25). Waters in this group are dominated by bicarbonate anions with a mix of sodium, calcium, and magnesium cations. This group is a low TDS end member for water quality within the greater Cuyama Valley Groundwater Basin and these conditions are only seen west of the Russell fault.

Group 3

Group 3 wells are located along the Cuyama River, west of the Russell fault. TDS of samples from this zone range from 560 to 3,000 mg/l. TDS measurements increase from south to north, with the highest levels measured in wells north of the Cuyama River. TDS also increases from east to west (downstream and nearer to Morales Canyon). Water character falls in a range from mixed bicarbonate-chloride-sulfate anions with dominant calcium-sodium cations (similar to Groups 1 and 2) to chloride-sulfate dominant anions with calcium-sodium dominant cations (similar to group 6). This falls in a linear trend in a Piper plot (Figure 26) illustrating varying degrees of mixing between waters sourced in the Sierra Madre Mountains and those sourced from the Cuyama River and Caliente Mountains. All samples are substantially lower in TDS than those immediately east of the fault (Figure 25) and show stronger influence from the Sierra Madre Mountains than from the Cuyama River and Caliente Mountains, as is apparent in the Group 6 samples east of the fault (Figure 26).

Group 4

Group 4 wells are all wells which have been drilled and completed since 2013. These wells all lie south of the Cuyama River and are completed in the upper Morales Formation. This zone had not been previously developed at the time of sampling, so samples represent natural equilibrium. Samples in this group range in TDS from 480 to 1,780 mg/l. TDS generally increases in a downstream direction and from south to north. The majority of samples contained mixed bicarbonate-chloride-sulfate anions and calcium-sodium dominant cations. These are consistent with Group 1 (alluvial) samples suggesting water recharge is mainly from Sierra Madre alluvial flow under natural conditions. A few of the wells downstream (high TDS wells) show a chloride-sulfate anion and calcium-magnesium cation content that is more consistent with Group 6 samples.

Group 5

Group 5 wells lie east of the Russell fault and South of the Turkey Trap Ridge fault in what the USGS has termed 'Northwest Sierra Madre Foothills' (Hanson et al. 2015). Wells sampled in this zone have TDS measurements ranging from 950 to 2,650 mg/l. Water character is dominated by chloride and sulfate anions with some bicarbonate where influence from the Sierra Madre runoff is present (Figure 26). Cations in this zone are mainly calcium and sodium. This combination suggests recharge from both the Cuyama River (Group 6) and the Sierra Madre Mountains which is consistent with previous studies (Upson and Worts 1951, Singer and Swarzenski 1970, Everett et al. 2013).

Group 6

Group 6 wells represent the second (high TDS) end member within the greater Cuyama Valley Groundwater Basin. These wells are found north of the Turkey Trap Ridge Fault and east of the Russell fault in what the USGS labels as the 'Western Basin' (Hanson et. al 2015). Wells sampled in this group are characterized by high TDS (up to 4,700 mg/l) (Figure 25) and are dominated by chloride-sulfate anions and calcium and magnesium cations (Figure 26). Source water for this group is from both the Cuyama River and the Caliente Mountains.

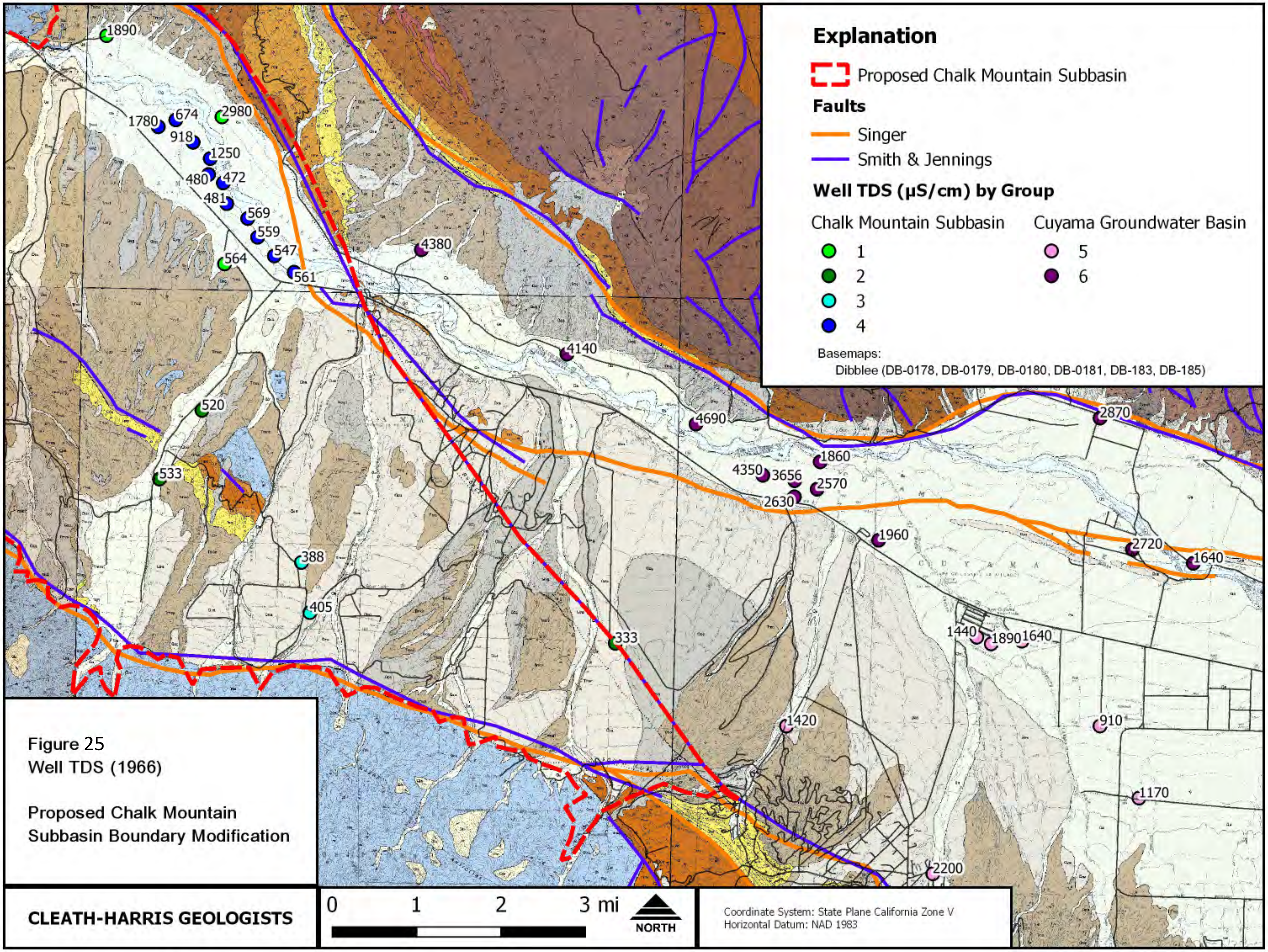

Figure 25
Well TDS (1966)

Proposed Chalk Mountain Subbasin Boundary Modification

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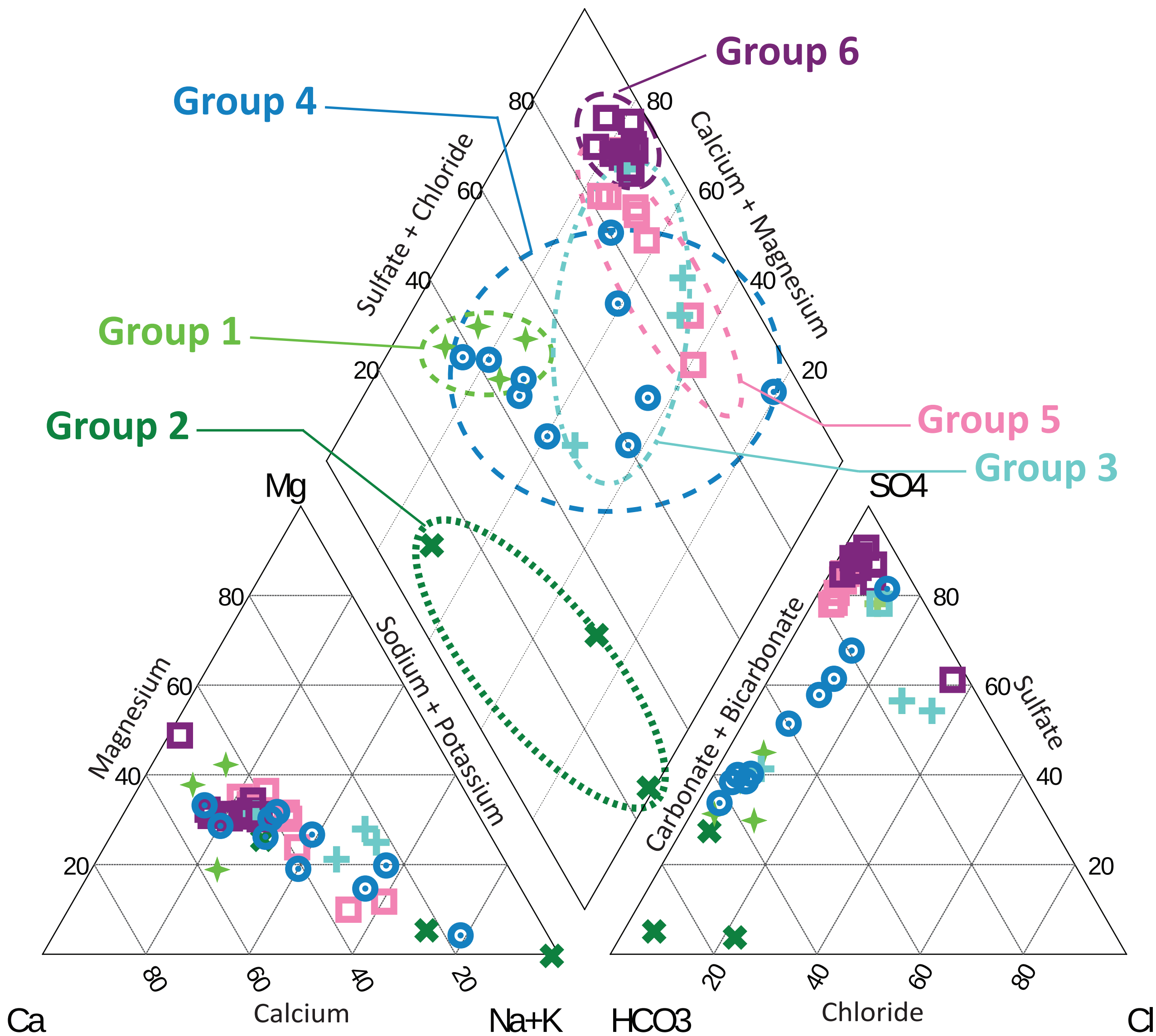
Coordinate System: State Plane California Zone V
Horizontal Datum: NAD 1983

Water Quality Across Proposed Chalk Mountain Sub-basin Boundary



LEGEND

Chalk Mountain Sub-basin Wells

- Highlands, Alluvium-west of Russell fault (Group 1)
- Highlands, Bedrock-west of Russell fault (Group 2)
- River Zone- west of Russell fault (Group 3)
- North Forks Ranch Wells- west of Russell fault (Group 4)

Cuyama Groundwater Basin Wells

- Cuyama Groundwater Basin-east of Russell fault (Group 5)
- River Zone- east of Russell fault, north of Turkey Trap Ridge fault (Group 6)

Figure 26
Water Quality across Proposed
Chalk Mountain Subbasin
Boundary Modifica on

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Summary of Water Quality

Water quality trends show distinct differences in composition and total dissolved solids across the Russell fault. This illustrates the dominance of different recharge sources, with the Cuyama River and runoff from the Caliente Range dominating recharge east of the fault and runoff from the Sierra Madre Mountains dominating recharge west of the fault. The apparent lack of mixing across the fault zone is consistent with previous finding of aquifer juxtaposition and fault sealing characteristics.

The only area of the basin that shows cross-fault mixing is the area just west of the fault along the Cuyama River (Group 4). This zone shows influence from the Cuyama River (which crosses the fault when flowing) and which represents the outflow of the Cuyama Valley Subbasin as previously discussed in the conceptual hydrologic model.

SUMMARY AND CONCLUSIONS

The creation of the Chalk Mountain Subbasin and Cuyama Valley Subbasin would allow for improved management within the basin. Current monitoring and management west of the Russell fault zone is limited in scope. Existing management tools and programs, including water level, water chemistry, and groundwater modeling, treat the proposed Chalk Mountain Subbasin boundary as a de facto management boundary. The basin area west of the Russell fault has both higher quality and lower use of groundwater than the eastern (and critically overdrafted) portions of the basin. Separate management would allow for appropriate monitoring and decision making that is based on conditions of each subbasin.

An analysis of the existing public and available data suggests a strong scientific case for creating the Chalk Mountain Subbasin. A summary of these finding follows:

- The basin 'finger' removed by the proposed external boundary modification is isolated by an unnamed fault just north of Gifford Ranch. This fault juxtaposes nonwater-bearing sediments against the water bearing basin sediments.
- Surface waters within the zone to be removed by the proposed external basin modification enter the Cuyama River downstream of the basin.
- Previous work by the USGS and others has focused on deeper oil related structure and has not adequately studied offset in shallow subsurface along the Russell fault zone.
- Structural cross sections across the proposed boundary show significant offset along the entire trace of the Russell fault. This offset cuts the entire (or nearly the entire) Morales Formation. Terrace mapping suggests this offset extends into the older alluvium.
- Shale Gouge Ratio (SGR) and Shale Smear Factor (SSF) analysis shows that, for the Morales Formation, the fault likely contains entrained clay across its entire surface for water-bearing zones and that that clay is likely to retard flow to a pressure differential of more than 110 psi. The Morales Formation is the key aquifer of concern for controlling groundwater flow.
- Springs located adjacent to the Russell fault indicate a barrier to groundwater flow
- Groundwater measurements adjacent to the fault are insufficient to provide conclusive water level offset across the fault.
- Groundwater chemistry shows clear variation across the fault. TDS is significantly higher to the east of the proposed boundary and shows a sharp decline to the west of the boundary. Both anion and cation correlations evidence different recharge sources for water across the boundary, except where infiltration from the surface flows of the Cuyama River is a common source of recharge.

DWR procedures require demonstrating the presence of a barrier for a scientific modification of an existing groundwater basin. The Russell fault has sufficient offset in the shallow, water-bearing sediments to create this barrier. SSF and SGR analysis shows that, based on lithology and fault offset, this barrier should strongly retard flow for the expected groundwater differentials. Groundwater quality shows a sharp contrast in TDS levels across the proposed boundary, which is also coupled with markedly different water chemistry (sources) on either side of the proposed boundary demonstrating the separation of groundwater along the fault. Lastly, while groundwater level data is sparse, it does suggest that levels on the west side of the fault are not declining as they are in the eastern portion of the basin. Fault bounded springs (Caliente Ranch Spring and Russell Spring) represent historic data points where groundwater was forced to the surface by this fault barrier. Existing data provides strong evidence for creating the Chalk Mountain and Cuyama Valley Subbasins.

If you have any questions or concerns please feel free to contact our office.

Sincerely,

CLEATH-HARRIS GEOLOGISTS, INC.

Timothy S. Cleath

Timothy S. Cleath, PG CHG CEG
Principal Hydrogeologist/Engineering Geologist

Neil D Currie

Neil D. Currie
Staff Geologist

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