Spring, Cave, Dry Lake and Delamar Valleys

SOUTHERN NEVADA WATER AUTHORITY

Presentation for
Rowley Testimony
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RESUME

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Education:

Ph.D. in geology (6/1968)—University of Texas at Austin (9/1964-6/1968). Dissertation: "Geology of the southern Sevier Plateau, Utah;" advisor J. Hoover Mackin

B.A. in geology (6/1964)—Carleton College, Northfield, Minnesota (9/1960-6/1964)

Honors and Awards:

2008: Lehi Hintze Award for Outstanding Contributions to the Geology of Utah, for 2008, by the Utah Geological Association and Utah Geological Survey, for career accomplishments in Utah (given annually)

1999: Distinguished Achievement Award, for career accomplishments, Carleton Alumni Association, Carleton College, Northfield, MN

1995: Dibblee Medal, by the Dibblee Geological Foundation, for career accomplishments in geologic mapping and field geology (a national medal, given annually)

1972-1987: Principal Investigator of 6 National Science Foundation grants to the USGS, totaling $519,000, for field and stateside research in Antarctica

1986: Meritorius Service Award, Department of the Interior

1986: Named geographic feature: Rowley Massif, in the Black Coast of the Antarctic Peninsula

1985, 1980: Named fossils, Otazamites rowleyi (a cycad leaf), Retroceramus rowleyi (a pelecypod)

1979: Named a Fellow of The Explorers Club, New York, N.Y.

1990-present: In Who's Who in America, Who's Who in the West, Who's Who in America (Science and Engineering), International Leaders in Achievement, Men of Achievement, Who's Who in Technology, American Men and Women of Science, Dictionary of International Biography, etc.

Current Employment:

Consulting Geologist
Geologic Mapping, Inc. (this is an S Corporation of which I am the President)
From 5/2001 to present

Work in progress—

(A) Contractor to Southern Nevada Water Authority (SNWA), Las Vegas, to provide the digital geologic framework to allow assessments of the effects of pumping, to aid ground-water-flow models, and to analyze applications for water in Spring, Cave, Delamar, Dry, and Snake Valleys and other basins in Lincoln and White Pine Counties, NV. Work includes preparing 1:250,000-scale geologic and hydrogeologic maps, cross sections, map explanations, analysis of flow paths and hydrogeology, and geologic reports aimed at securing water rights in meetings with the Nevada State Engineer as well as for the Bureau of Land Management Environmental Impact Statement for the planned pipeline to bring water to Las Vegas; providing expert-witness testimony; and helping site production well fields (1/09-present). Collaborate with and assist Gary Dixon (Southwest Geology, Inc.), Andrew Burns of SNWA, and others at SNWA in their long-term study of the Great Salt Lake Desert and White River ground-water flow systems in a 40,000 mi^2 area of E Nevada and W Utah, including preparing reports for publication.

Geology and Geophysics of Spring, Cave, Dry Lake, and Delamar Valleys, White Pine and Lincoln Counties and Adjacent Areas, Nevada and Utah: The Geologic Framework of Regional Groundwater Flow Systems

PRESENTATION TO THE OFFICE OF THE NEVADA STATE ENGINEER

Prepared by

SOUTHERN NEVADA
WATER AUTHORITY

June 2011

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QTb	Quaternary and Tertiary thin basalt flows and cinder cones
Ts4	Tertiary fluvial and lacustrine sediments
Tt4	Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
Ta4	Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
Tr4	Tertiary high-silica rhyolite lava flows and volcanic domes
Tr3	Tertiary low-silica rhyolite lava flows and volcanic domes
Ta3	Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
Ts3	Tertiary mostly fluvial tuffaceous sandstone and bedded airfall tuff
Tt3	Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
Ts2	Tertiary mostly fluvial tuffaceous sandstone and bedded airfall tuff
Ta2	Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
Tr2	Tertiary low-silica rhyolite lava flows and volcanic domes
Tt2	Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
Tt1	Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
Tr1	Tertiary low-silica rhyolite lava flows and volcanic domes
Ta1	Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
Ts1	Tertiary fluvial and lacustrine sediments
Tmb	Tertiary intracaldera megabreccia
Ti	Tertiary intrusive rocks
TKi	Tertiary-Cretaceous intrusive rocks
Ki	Cretaceous intrusive rocks
Ks	Upper and Lower Cretaceous sedimentary rocks, undivided
Ji	Jurassic intrusive rocks
₹s	Triassic sedimentary rocks, undivided
Pp	Upper and Lower Permian Park City Group, undivided
Par	Permian Arcturus Formation and Rib Hill Sandstone
Pa	Permian Arcturus Formation
Pr	Lower Permian Rib Hill Sandstone
PIP	Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone, undivided
IP	Pennsylvanian Ely Limestone
MDd	Upper Mississippian to Upper Devonian Diamond Peak Formation, Chainman Shale, Joana Limestone, and Pilot Shale, undivided
Md	Upper Mississippian Diamond Peak Formation
Mc	Upper Mississippian Chainman Shale
MD	Lower Mississippian to Upper Devonian Joana Limestone and Pilot Shale, undivided
D€	Devonian to Upper Cambrian sedimentary rocks, undivided
DS	Devonian and Silurian sedimentary rocks, undivided
Du	Devonian carbonate sedimentary rocks, undivided
Dd	Upper and Middle Devonian Devils Gate Formation
Dg	Upper and Middle Devonian Guilmette Formation
Dn	Middle and Lower Devonian Nevada Formation
Ds	Middle and Lower Devonian Simonson and Sevy Dolomites
SOu	Silurian and Upper Ordovician dolomite, undivided
Ol	Middle and Lower Ordovician, mostly Eureka Quartzite and the Pogonip Goup
€c	Cambrian carbonate sedimentary rocks, undivided
€u	Lower Ordovician? And Upper Cambrian limestone and shale, undivided
€m	Upper and Middle Cambrian limestone and shale
€p€s	Middle Cambrian to Late Proterozoic sedimentary rocks
p€	Late to Early Proterozoic metamorphosed and crystalline Precambrian basement rocks
	Open Water

Regional Faults

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed. Bar and ball on downthrown side.

Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed. Sawteeth on upper plate.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed. Sawteeth on upper plate.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed. Bar and ball on downthrown side.

Subsidiary Faults

Normal Fault
Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Bar and ball on downthrown side.

Strike-slip Fault
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Quaternary Normal Fault
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Caldera Boundary
Solid where known; dashed where inferred; dotted where concealed

Cross Sections (Plates 4 and 5)

Major Road

Transverse Zone
(Zone of possible disruption)

National Park Service

Oil Well Data Used in Cross Sections
Nevada: Nevada Bureau of Mines and Geology
Utah: Utah Division of Oil, Gas and Mining

Wells

Town

Strike and Dip of Beds

Overturned Beds

SCALE 1:250,000

Projection: UTM Zone 11 NAD83

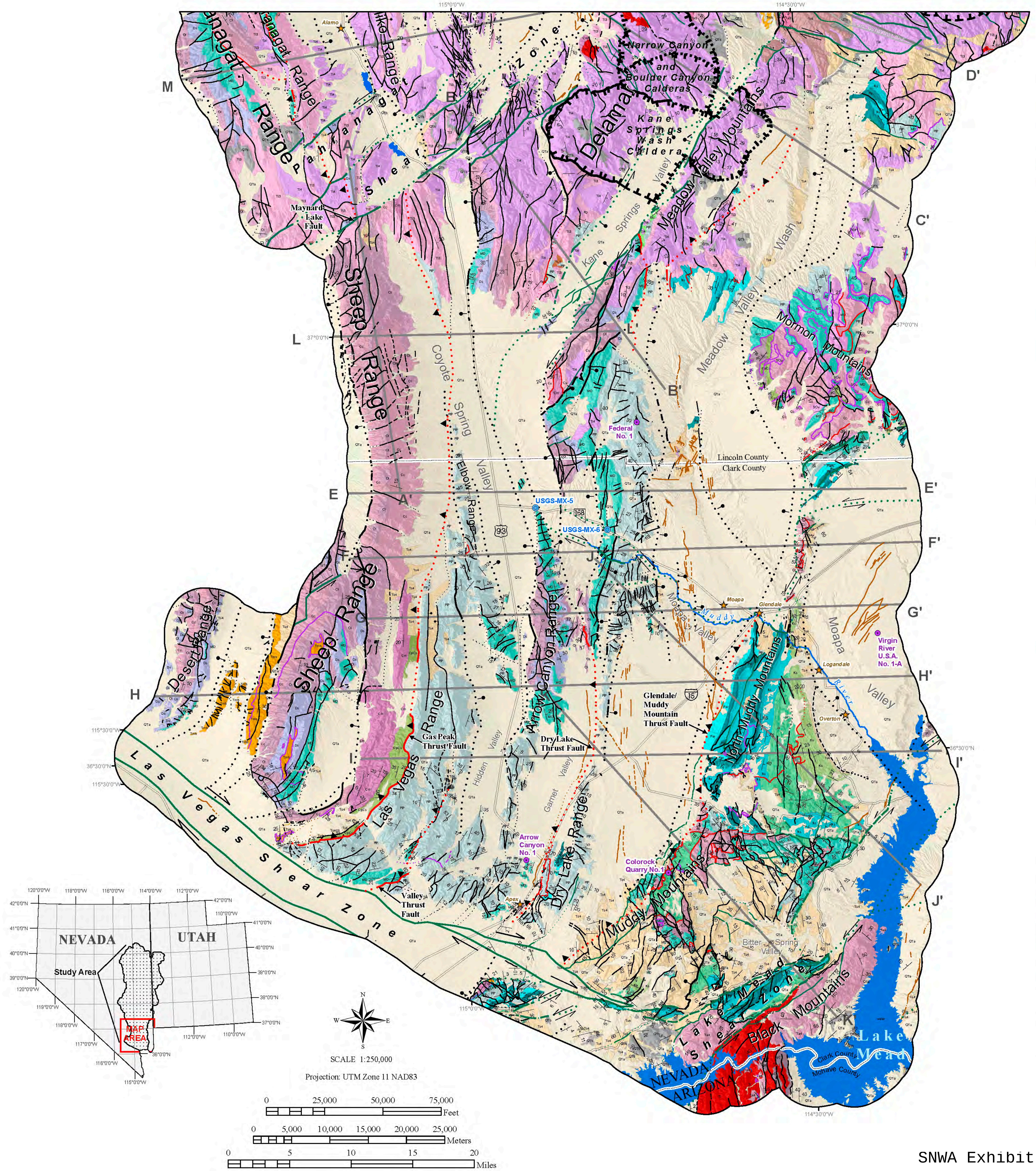
0 25,000 50,000 75,000 Feet
0 5,000 10,000 15,000 20,000 25,000 Meters
0 5 10 15 20 Miles

PLATE 1. GEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

SNWA Exhibit 58

SOUTHERN NEVADA WATER AUTHORITY

MAP ID 18286-3211 05/17/2011 JAB/BP



Explanation

Geologic Units

- QTa — Quaternary and Tertiary basin-fill deposits
- QTb — Quaternary and Tertiary thin basalt flows and cinder cones
- Ts4 — Tertiary fluvial and lacustrine sediments
- Tt4 — Tertiary poorly-to-densely welded ash-flow tuff and interbedded airfall tuff
- Ta4 — Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
- Tr4 — Tertiary high-silica rhyolite lava flows and volcanic domes
- Ta3 — Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
- Tt3 — Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
- Tt2 — Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
- Ts1 — Tertiary fluvial and lacustrine sediments
- Tmb — Tertiary megabreccia
- Ti — Tertiary intrusive rocks
- Ks — Upper and Lower Cretaceous sedimentary rocks, undivided
- Js — Jurassic sedimentary rocks, undivided
- T̄s — Triassic sedimentary rocks, undivided
- Pp — Upper and Lower Permian Park City Group, undivided
- Par — Permian Arcturus Formation and Rib Hill Sandstone
- PIP — Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone, undivided
- Md — Upper Mississippian Diamond Peak Formation
- Mc — Upper Mississippian Chainman Shale
- MD — Lower Mississippian to Upper Devonian Joana Limestone and Pilot Shale, undivided
- Ds — Middle and Lower Devonian Simonson and Sevy Dolomites
- Du — Devonian carbonate sedimentary rocks, undivided
- SOu — Silurian and Upper Ordovician dolomite, undivided
- Ol — Middle and Lower Ordovician, mostly Eureka Quartzite and the Pogonip Goup
- Ꞓc — Cambrian carbonate sedimentary rocks, undivided
- Ꞓu — Lower Ordovician? And Upper Cambrian limestone and shale, undivided
- Ꞓm — Upper and Middle Cambrian limestone and shale
- ꞒpꞒs — Middle Cambrian to Late Proterozoic sedimentary rocks
- pꞒ — Late to Early Proterozoic metamorphosed and crystalline Precambrian basement rocks
- Open Water

Regional Faults

- Normal Fault — Solid where known; Dashed where inferred; dotted where concealed. Bar and ball on downthrown side.
- Strike-slip Fault — Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.
- Thrust Fault — Solid where known; Dashed where inferred; dotted where concealed. Sawteeth on upper plate.
- Detachment Fault — Solid where known; Dashed where inferred; dotted where concealed. Sawteeth on upper plate.
- Quaternary Normal Fault — Solid where known; Dashed where inferred; dotted where concealed.

Subsidiary Faults

- Normal Fault — Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Bar and ball on downthrown side.
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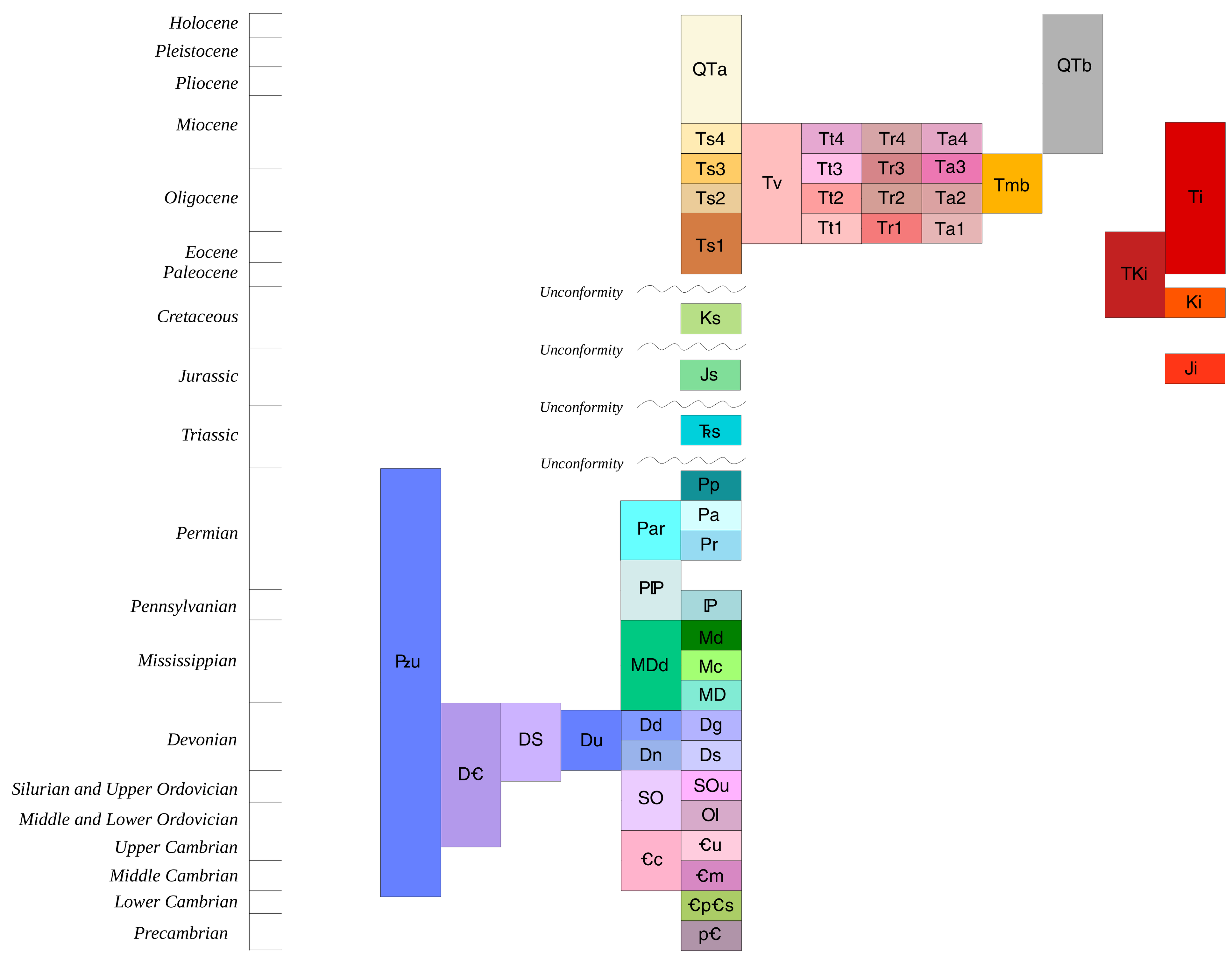
- Town
- Strike and Dip of Beds
- Overturned Beds
- Oil Well Data Used in Cross Sections — Nevada: Nevada Bureau of Mines and Geology
- Well

SNWA Exhibit 58

SOUTHERN NEVADA WATER AUTHORITY

MAP ID 18287-3211 06/01/2011 BP/JAB

PLATE 2. GEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA , AND ADJACENT AREAS, ARIZONA



QTa Surficial and basin-fill deposits (Holocene to upper Miocene)—Unconsolidated to moderately consolidated, locally tuffaceous beds of sand, gravel, silt, and minor limestone deposited mostly by streams and small playa lakes. Generally thin but, where unit fills basin-range-fault-bounded basins, may be 0-5000 feet thick and forms the upper valley-fill aquifer. Some basin-fill deposits bear local names, including the Muddy Creek Formation (southern part of Plate 2), Panaca Formation (southern part of Plate 1), Horse Camp Formation (northwestern part of Plate 1), and Salt Lake Formation (northeastern part of Plate 1).

QTb Basalt lava flows (Holocene to lower Miocene)—Resistant, thin, basalt lava flows and cinder cones. The mafic end of the bimodal volcanic sequence that is synchronous with basin-range extensional faulting.

Ts4 Sedimentary rocks, unit 4 (Miocene)—Moderately to well consolidated, mostly fluvial sandstone, conglomerate, and minor lacustrine limestone. Primarily the Horse Spring Formation (11 to 20 Ma), a basal basin-fill sedimentary unit that is locally thick (3000+ feet) in the southern part of Plate 2.

Ts3 Sedimentary rocks, unit 3 (Miocene and Oligocene)—Moderately to well consolidated, thin, mostly fluvial, tuffaceous sandstone and bedded airfall tuff

Ts2 Sedimentary rocks, unit 2 (Oligocene)—Moderately to well consolidated, thin, mostly fluvial, tuffaceous sandstone and conglomerate. Includes the Gilmore Gulch Formation, with an age of about 30 Ma, in the northwestern part of Plate 1.

Ts1 Sedimentary rocks, unit 1 (Oligocene to Upper Cretaceous?)—Moderately to well consolidated, mostly fluvial sandstone, conglomerate, and minor lacustrine limestone. Primarily the Sheep Pass Formation, but in the central part of Plate 1, includes the Paleocene and Upper Cretaceous(?) Grapevine Wash Formation and the Eocene and Paleocene Claron Formation. Includes the Fowkes Formation and White Sage Formation in the northeastern part of Plate 1. Unit in most places underlies all volcanic rocks.

Tv Volcanic rocks (Miocene to Eocene)—Unit shown only in Plates 4, 5, 6, 7, 8, and 9, where it is referred to as the volcanic aquifer. May be several thousand feet thick in many places, and in calderas and near other source vents, may be many thousands of feet thick. On Plates 1 and 2, unit is separated into several rock types based on age, following the mapping strategy of Ekren et al, (1977).

Tt4 Ash-flow tuff and interbedded airfall tuff, unit 4 (Miocene)—Poorly to densely welded, bimodal high-silica rhyolite and locally peralkaline ash-flow tuff and related airfall tuffs. Includes the tuff of Honeycomb Rock (12.0 Ma), Ox Valley Tuff (14.0 Ma), tuff of Etna (14.0 Ma), tuff of Rainbow Canyon (15.6 Ma), tuff of Acklin Canyon (17.1 Ma), and tuff of Dow Mountain (17.4 Ma), derived from the Caliente caldera complex. Includes the Kane Wash Tuff (14.4 to 14.7 Ma), the tuff of Boulder Canyon (15.1 Ma), and the tuff of Narrow Canyon (15.8 Ma), derived from the Kane Springs Wash caldera complex.

Tt3 Ash-flow tuff and interbedded airfall tuff, unit 3 (Miocene and Oligocene)—Poorly to densely welded, calc-alkaline, low-silica rhyolite to dacite ash-flow tuff and related airfall tuffs. Includes the tuff of Teepee Rocks (17.8 Ma), Hiko Tuff (18.3 Ma), Racer Canyon Tuff (18.7 Ma), and both Bauers Tuff Member (22.8 Ma) and Swett Tuff Member (23.7 Ma) of the Condor Canyon Formation, all derived from the Caliente caldera complex. Also includes the Harmony Hills Tuff (22.0 Ma), probably derived from the eastern Bull Valley Mountains; the Leach Canyon Formation (23.8 Ma), probably derived from the Caliente caldera complex; the Bates Mountain Tuff (22.8 Ma), derived from Lander County, Nevada; and the tuff of Saulsbury Wash (21.6 Ma), the Pahranagat Formation (22.6 Ma), the tuff of White Blotch Spring (24 to 25 Ma), the tuff of Kiln Canyon (24.1 to 25.1 Ma), the tuff of Lunar Cuesta (24.6 Ma), the tuff of the Quinn Canyon Range, and the Shingle Pass Tuff (26.4), all derived from the central Nevada caldera complex; and the tuff of Bald Mountain (about 25 Ma), derived from the Bald Mountain caldera in the Groom Range.

Tt2 Ash-flow tuff and interbedded airfall tuff, unit 2 (Oligocene)—Poorly to densely welded, calc-alkaline, low-silica rhyolite to dacite and trachydacite ash-flow tuff and related airfall tuffs. Includes the Isom Formation (about 27 Ma), probably derived from the Indian Peak caldera complex; the outflow Monotony Tuff (27.3 Ma), the intracaldera tuff of Goblin Knobs (27.3 Ma), and the tuff of Hot Creek Canyon (30.0 Ma), all derived from the central Nevada caldera complex; the outflow Windous Butte Formation (31.4 Ma) and intracaldera tuff of Williams Ridge and Morey Peak (31.3 Ma), derived from the Williams Ridge caldera of the central Nevada caldera complex; and the Needles Range Group (29 to 32 Ma), derived from the Indian Peak caldera complex.

Tt1 Ash-flow tuff and interbedded airfall tuff, unit 1 (Oligocene and Eocene)—Poorly to densely welded, calc-alkaline, low-silica rhyolite to dacite and trachydacite ash-flow tuff and related airfall tuffs. Deposited in the northern part of Plate 1. Includes the Pancake Summit Tuff (33.7 Ma), derived from the Broken Back caldera west of Eureka; the Stone Cabin Formation (35.4 Ma), derived from an unknown caldera in or near northern Railroad Valley; and the Kalamazoo Tuff (35 Ma), derived from an unknown source probably in the northern Schell Creek Range or beneath adjacent northern Spring Valley. In Utah, includes the Tunnel Spring Tuff (35.4 Ma).

Tr4 Rhyolite lava flows, unit 4 (Miocene)—High-silica rhyolite lava flows and volcanic domes, mostly in and near the Caliente and Kane Springs Wash caldera complexes.

Tr3 Rhyolite lava flows, unit 3 (Miocene and Oligocene)—Low-silica rhyolite lava flows and volcanic domes, mostly in and near the Indian Peak, Caliente, and central Nevada caldera complexes.

Tr2 Rhyolite lava flows, unit 2 (Oligocene)—Low-silica rhyolite lava flows and volcanic domes, mostly in and near the central Nevada and Indian Peak caldera complexes.

Tr1 Rhyolite lava flows, unit 1 (Oligocene and Eocene)—Low-silica rhyolite lava flows and volcanic domes, exposed in the northern part of Plate 1.

Ta4 Intermediate-composition lava flows, unit 4 (Miocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Includes andesite of the Hamblin-Cleopatra volcano (11.5 to 14.2 Ma) in the Lake Mead area.

Ta3 Intermediate-composition lava flows, unit 3 (Miocene and Oligocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Includes andesite between the Racer Canyon Tuff and Condor Canyon Formation in the southeastern part of Plate 2, between the Caliente and Kane Springs Wash caldera complexes, and in and near the Indian Peak and central Nevada caldera complexes.

Ta2 Intermediate-composition lava flows, unit 2 (Oligocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Includes andesite in and near the Indian Peak caldera complex and in the southern Egan Range.

Ta1 Intermediate-composition lava flows, unit 1 (Oligocene and Eocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Exposed in the northern part of Plate 1. In the northeastern part of Plate 1 includes thin ash-flow tuffs, notably the Kalamazoo tuff. In Utah, includes the Horn Silver Andesite.

Tmb Megabreccia (Miocene and Oligocene)—Masses of mostly Paleozoic sedimentary rocks and intertongued volcanic breccia deposited within calderas from landsliding of the oversteepened caldera margins following caldera subsidence as a result of rapid eruptions of ash-flow tuff. Includes rocks in the Indian Peak caldera complex, Caliente caldera complex and central Nevada caldera complex. Includes gravity slides west of the Sheep Range and Beaver Dam Mountains.

Ti Intrusive rocks (Miocene to Paleocene)—Mostly silicic, calc-alkaline plutons.

TKi Intrusive rocks (Miocene to Cretaceous)—Mostly silicic, calc-alkaline plutons.

Ki Intrusive rocks (Upper Cretaceous)—Mostly silicic, calc-alkaline plutons that accompanied Sevier deformation.

Ks Sedimentary rocks, undivided (Upper and Lower Cretaceous)—Sevier-age, mostly thin, fluvial synorogenic clastic deposits, including the Baseline Sandstone (Upper and Lower Cretaceous) and Willow Tank Formation (Upper Cretaceous) in the southern part of Plate 2, and the Iron Springs Formation (Upper Cretaceous), Cedar Mountain Formation (Upper Cretaceous), and Dakota Sandstone (Upper Cretaceous) in the southeastern part of Plate 2; and the Newark Canyon Formation (Paleocene? to Lower Cretaceous?) in the northern part of Plate 1.

Ji Intrusive rocks (Jurassic)—Mostly silicic, calc-alkaline plutons that accompanied Sevier deformation.

Js Sedimentary rocks, undivided (Jurassic)—Includes, in the southeastern part of Plate 2, the mostly marine Carmel and underlying Temple Cap formations (Middle Jurassic). Also in the southeastern part of Plate 2, includes the eolian Navajo Sandstone and mostly fluvial Kayenta and Moenave formations, all Lower Jurassic. Mostly clastic units. In the southern part of Plate 2, the Aztec Sandstone is the equivalent of the Navajo. Includes the Dunlop Formation (Lower Jurassic) in the northwestern part of Plate 1.

Ꞧs Sedimentary rocks, undivided (Triassic)—Includes, in the southeastern part of Plate 2, the mostly fluvial Chinle Formation (Upper Triassic) and mostly fluvial Moenkopi Formation (Middle? and Lower Triassic). Includes the Luning Formation (Upper Triassic) in the northwestern part of Plate 1. In the northeastern part of Plate 1, includes the Thaynes Formation (Lower Triassic). The majority of these rocks are clastic.

Ꝑzu Paleozoic sedimentary rocks, undivided—Shown on Plates 4, 5, 8, and 9, where rocks in the hanging wall of the Snake Range decollement are buried by younger rocks.

Pp Park City Group, undivided (Upper and Lower Permian)—From top to base, consists of the Gerster Limestone (Upper Permian), Plympton Formation (Upper and Lower Permian), Kaibab Limestone (Lower Permian), and Toroweap Formation (Lower Permian). These make up the top of the upper carbonate aquifer.

Par Arcturus Formation and Rib Hill Sandstone, undivided (Lower Permian)—Included within the upper carbonate aquifer. Includes the Pequop Formation in Elko County, a redbed unit in the southern part of Plate 2, and the Queantoweap Sandstone in the southeastern part of Plate 2.

Pa Arcturus Formation (Lower Permian)—Predominantly carbonate rocks in the northern part of Plate 1, thickening eastward.

Pr Rib Hill Sandstone (Lower Permian)—Only in the northwestern part of Plate 1.

PꟼP Riepe Spring Limestone and Ely Limestone, undivided (Lower Permian and Pennsylvanian)— Mapped only in the northern part of Plate 1. The Riepe Spring Limestone (Lower Permian) is exposed in the northwestern part of Plate 1. Includes the Brock Canyon Formation (Permian and/or Pennsylvanian) in the northwestern part of Plate 1; the Oquirrh Group (Lower Permian and Pennsylvanian) in the northeastern part of Plate 1; and the Bird Spring Formation (Lower Permian to Upper Mississippian) in Clark County, Nevada and the Pakoon Formation (Lower Permian) in Utah.

ꟼP Ely Limestone (Pennsylvanian)—May include Missippian rocks at its base. Mapped mostly in the central and northern part of Plate 1, thickening eastward. Includes the Wildcat Peak Formation in the northwestern part of Plate 1 and the Callville Limestone in the southern and eastern part of Plate 2.

MDd Diamond Peak Formation, Chainman Shale, Joana Limestone, and Pilot Shale, undivided (Upper Mississippian to Upper Devonian)

Md Diamond Peak Formation (Upper Mississippian)—Only in the northwestern part of Plate 1. This is a clastic unit derived from erosion of the Antler highland, including the Roberts Mountain thrust formed during the Antler deformational event. Includes the Scotty Wash Quartzite in the southwestern part of Plate 2.

Mc Chainman Shale (Upper Mississippian)—A clastic confining unit that has a similar origin to the Diamond Peak Formation. The two make up the upper aquitard in the northern half of Plate 1. Thus for this part of the map area, it separates the upper from the lower carbonate aquifer; in the area of Plate 2, the Chainman is thin and does not constitute a significant regional aquitard.

MD Joana Limestone and Pilot Shale, undivided (Lower Mississippian to Upper Devonian)—The Joana Limestone (Lower Mississippian) and Pilot Shale (Lower Mississippian and Upper Devonian) make up the top of the lower carbonate aquifer in the northern half of Plate 1. Includes local Lower Mississippian units Mercury Limestone and Bristol Pass Limestone. Includes the Rogers Spring Limestone (Lower Mississippian) and Monte Cristo Limestone (Upper and Lower Mississippian) in the southern part of Plate 2; the Eleana Formation (Mississippian and Upper Devonian) in the western part of Plate 2; the Webb Formation (Lower Mississippian) in Elko County ; the Ochre Mountain Limestone and underlying Woodman Formation (Lower Mississippian) in the eastern part of Plate 1; and the West Range Limestone (Upper Devonian) in northern Lincoln County. May include, at the top, thin deposits of the Chainman Shale.

DЄ Devonian to Upper Cambrian carbonate and clastic rocks, undivided.

DS Devonian and Silurian sedimentary rocks, undivided—Only shown on some cross sections (Plates 4, 5, 8, and 9).

Du Devonian carbonate sedimentary rocks, undivided—Includes the Woodruff Formation (Upper and Middle Devonian) in Elko County; and the Muddy Peak Limestone (Upper and Middle? Devonian) in the southern part of Plate 2.

Dd Devils Gate Formation (Upper and Middle Devonian)—The western equivalent of the Guilmette Formation.

Dg Guilmette Formation (Upper and Middle Devonian)—Mapped throughout, except in the western part of Plate 1. Includes the Sultan Limestone in Clark County.

Dn Nevada Formation (Middle and Lower Devonian)—The western equivalent of the Simonson and Sevy Dolomites. Includes the Cockalorum Wash Formation, also in the western part of Plate 1.

Ds Simonson Dolomite (Middle and Lower Devonian) and Sevy Dolomite, undivided (Lower Devonian)—Mapped in all but the western part of Plate 1.

SO Silurian and Ordovician sedimentary rocks, undivided—Shown on some cross sections (Plates 4, 5, 8, and 9).

SOu Upper part (Silurian and Upper Ordovician)--Includes the Laketown Dolomite (Silurian), Fish Haven Dolomite (Upper Ordovician), Ely Springs Dolomite (Upper Ordovician), and Hanson Creek Formation (Upper Ordovician). Includes the Roberts Mountains Formation and the Lone Mountain Dolomite in the northwestern part of Plate 1.

Ol Lower part (Middle and Lower Ordovician)—Mostly the Eureka Quartzite (Middle Ordovician) and the Pogonip Group (Middle and Lower Ordovician). Includes the Vinini Formation and Valmy Formation in the northwestern part of Plate 1. Includes the Ely Springs Dolomite where it is thin in Clark County. In Utah, includes the Crystal Peak, Watson Ranch, and Fillmore formations and the House Limestone.

Єc Cambrian carbonate sedimentary rocks, undivided—Shown only on some cross sections (Plates 4, 5, 8, and 9).

Єu Upper part (Lower Ordovician? and Upper Cambrian)—Includes the Notch Peak Limestone, Orr Formation, Windfall Formation, Nopah Limestone, Dunderberg Shale, and Corset Spring Shale. In the extreme southwestern part of Plate 2, includes the Emigrant Formation (Upper and Middle Cambrian).

Єm Middle part (Upper and Middle Cambrian)—Mostly the Highland Peak Formation and its southwestern equivalent, the Bonanza King Formation. In Nevada, includes local units known as the Pole Canyon Limestone, Lincoln Peak Formation, Patterson Pass Shale, Hamburg Formation, Secret Canyon Shale, Geddes Limestone, and Eldorado Formation. Includes the Muav Limestone in eastern Clark County. In Utah, includes the Wah Wah Summit, Trippe, Pierson Cove, Eye of Needle, Swasey, Whirlwind, Dome, Chisholm, and Howell formations. This unit is a thick limestone sequence that marks the base of the lower carbonate aquifer.

ЄpЄs Lower part (Middle Cambrian to Late Proterozoic)—Chisholm Shale (Middle Cambrian), Lyndon Limestone (Middle Cambrian), Pioche Shale (Middle and Lower Cambrian), Carrara Formation (Middle and Lower Cambrian), Stella Lake Quartzite (Lower Cambrian), Prospect Mountain Quartzite (Lower Cambrian and Late Proterozoic), and Johnnie Formation (Late Proterozoic). The Prospect Mountain, in turn, has been subdivided into the Zabriskie Quartzite (Lower Cambrian), Wood Canyon Formation (Lower Cambrian), and Sterling Quartzite (Lower Cambrian and Late Proterozoic). Locally includes the Reed Dolomite (Lower Cambrian) and underlying Wyman Formation (Lower Cambrian?) in the southwestern part of Plate 2.

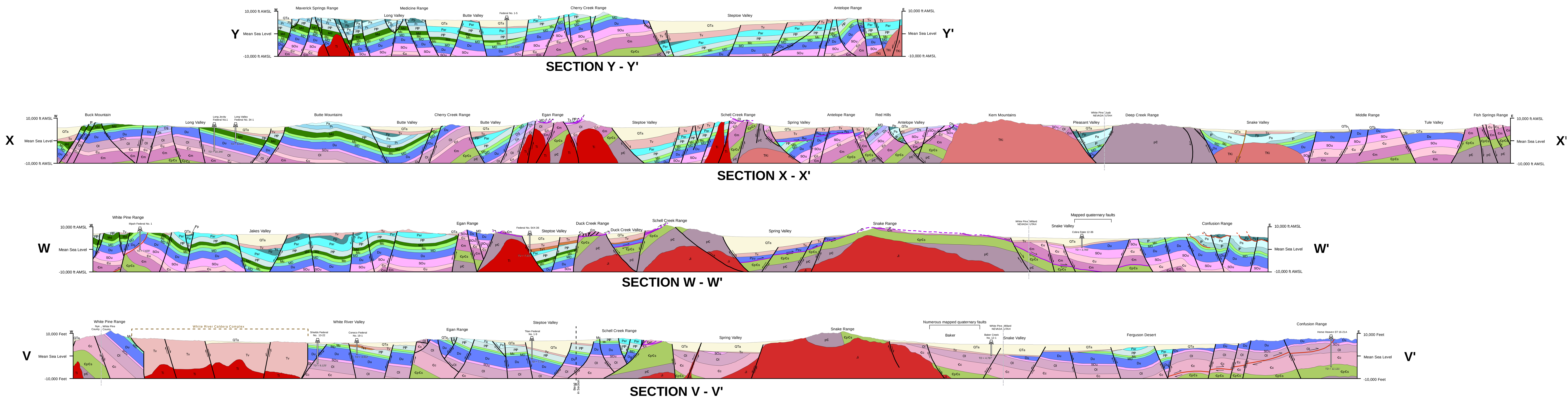
pЄ Metamorphosed and crystalline Precambrian basement rocks (Late to Early Proterozoic)—Throughout most of Plates 1 and 2, consists of metamorphosed quartzite of Late Proterozoic age, namely the McCoy Creek Group and, in Utah, also the underlying Trout Creek Group. Locally, in the southern part of Plate 2, includes crystalline basement rocks.

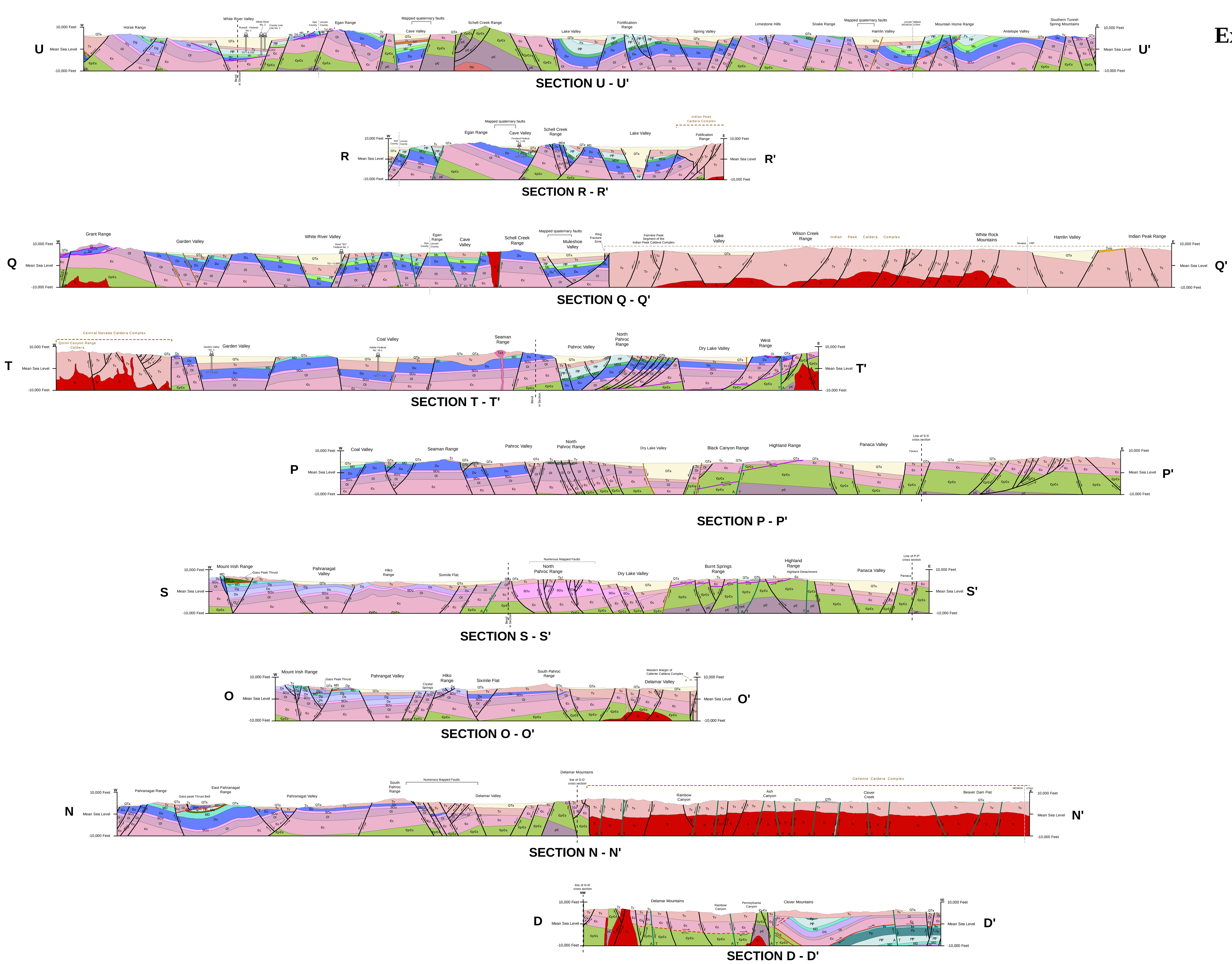
Open Water

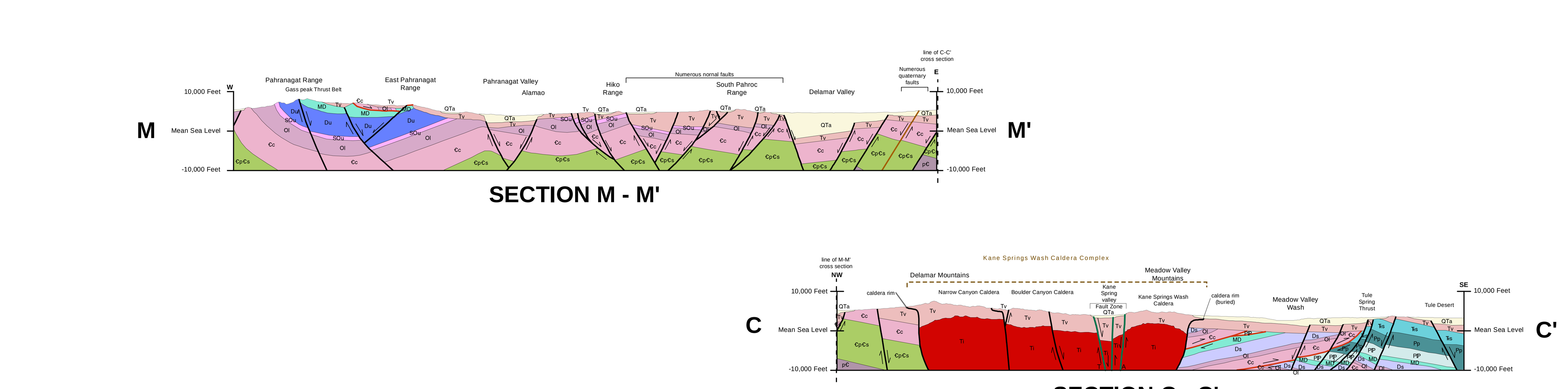
PLATE 3. EXPLANATION OF GEOLOGIC UNITS FOR THE MAPS AND CROSS SECTIONS OF PLATES 1, 2, 4, AND 5.

SNWA Exhibit 58

MAP ID 18288-3211 04/20/2011 BP







Explanation of Geologic Units

Shown on Cross Section

QTa	Quaternary and Tertiary basin-fill deposits
QTb	Quaternary and Tertiary thin basalt flows and cinder cones
Tv	Tertiary volcanic ash-flows, flows and ash-fall tuffs
Ta3	Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
Ts1	Tertiary fluvial and lacustrine sediments
Tmb	Tertiary intracaldera megabreccia
Ti	Tertiary intrusive rocks
TKi	Tertiary-Cretaceous intrusive rocks
Ki	Cretaceous intrusive rocks
Ks	Upper and Lower Cretaceous sedimentary rocks, undivided
Ji	Jurassic intrusive rocks
Js	Jurassic sedimentary rocks, undivided
Ћs	Triassic sedimentary rocks, undivided
Pu	Paleozoic Rocks, Undifferentiated
Pp	Upper and Lower Permian Park City Group, undivided
Par	Permian Arcturus Formation and Rib Hill Sandstone
Pa	Permian Arcturus Formation
Pr	Lower Permian Rib Hill Sandstone
PIP	Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone, undivided
IP	Pennsylvanian Ely Limestone
MDd	Upper Mississippian to Upper Devonian Diamond Peak Formation, Chainman Shale, Joana Limestone, and Pilot Shale, undivided
Md	Upper Mississippian Diamond Peak Formation
Mc	Upper Mississippian Chainman Shale
MD	Lower Mississippian to Upper Devonian Joana Limestone and Pilot Shale, undivided
DS	Devonian and Silurian sedimentary rocks, undivided
Du	Devonian carbonate sedimentary rocks, undivided
Dd	Upper and Middle Devonian Devils Gate Formation
Dg	Upper and Middle Devonian Guilmette Formation
Dn	Middle and Lower Devonian Nevada Formation
Ds	Middle and Lower Devonian Simonson and Sevy Dolomites
SOu	Silurian and Upper Ordovician dolomite, undivided
Ol	Middle and Lower Ordovician, mostly Eureka Quartzite and the Pogonip Goup
€c	Cambrian carbonate sedimentary rocks, undivided
€u	Lower Ordovician? And Upper Cambrian limestone and shale, undivided
€m	Upper and Middle Cambrian limestone and shale
€p€s	Middle Cambrian to Late Proterozoic sedimentary rocks
p€	Late to Early Proterozoic metamorphosed and crystalline Precambrian basement rocks

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

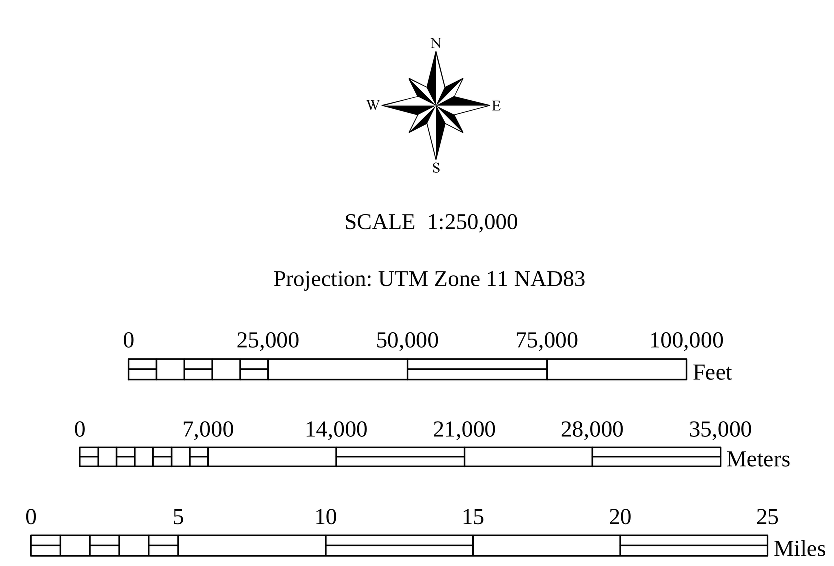
Strike-slip Fault (T / A)
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement. T= Towards, A = Away.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Well Name
TD=1,234'
Oil Well Data Used in Cross Sections
TD = Total Depth (Feet)



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SOUTHERN NEVADA WATER AUTHORITY

PLATE 4. CROSS SECTIONS SHOWING GEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

MAP ID 18433-3211 05/25/2011 JAB/BP

Explanation of Geologic Units
Shown on Cross Section

Unit	Description
QTa	Quaternary and Tertiary basin-fill deposits
Tv	Tertiary volcanic ash-flows, flows and ash-fall tuffs
Ts4	Tertiary fluvial and lacustrine sediments
Tmb	Tertiary megabreccia
Ti	Tertiary intrusive rocks
Ks	Upper and Lower Cretaceous sedimentary rocks, undivided
Js	Jurassic sedimentary rocks, undivided
Ŧs	Triassic sedimentary rocks, undivided
Pp	Upper and Lower Permian Park City Group, undivided
PIP	Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone, undivided
MD	Lower Mississippian to Upper Devonian Joana Limestone and Pilot Shale, undivided
D€	Devonian to Upper Cambrian sedimentary rocks, undivided
DS	Devonian and Silurian sedimentary rocks, undivided
Du	Devonian carbonate sedimentary rocks, undivided
Ds	Middle and Lower Devonian Simonson and Sevy Dolomites
Ol	Middle and Lower Ordovician, mostly Eureka Quartzite and the Pogonip Goup
€c	Cambrian carbonate sedimentary rocks, undivided
€p€s	Middle Cambrian to Late Proterozoic sedimentary rocks
p€	Late to Early Proterozoic metamorphosed and crystalline Precambrian basement rocks

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement. T= Towards, A = Away.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

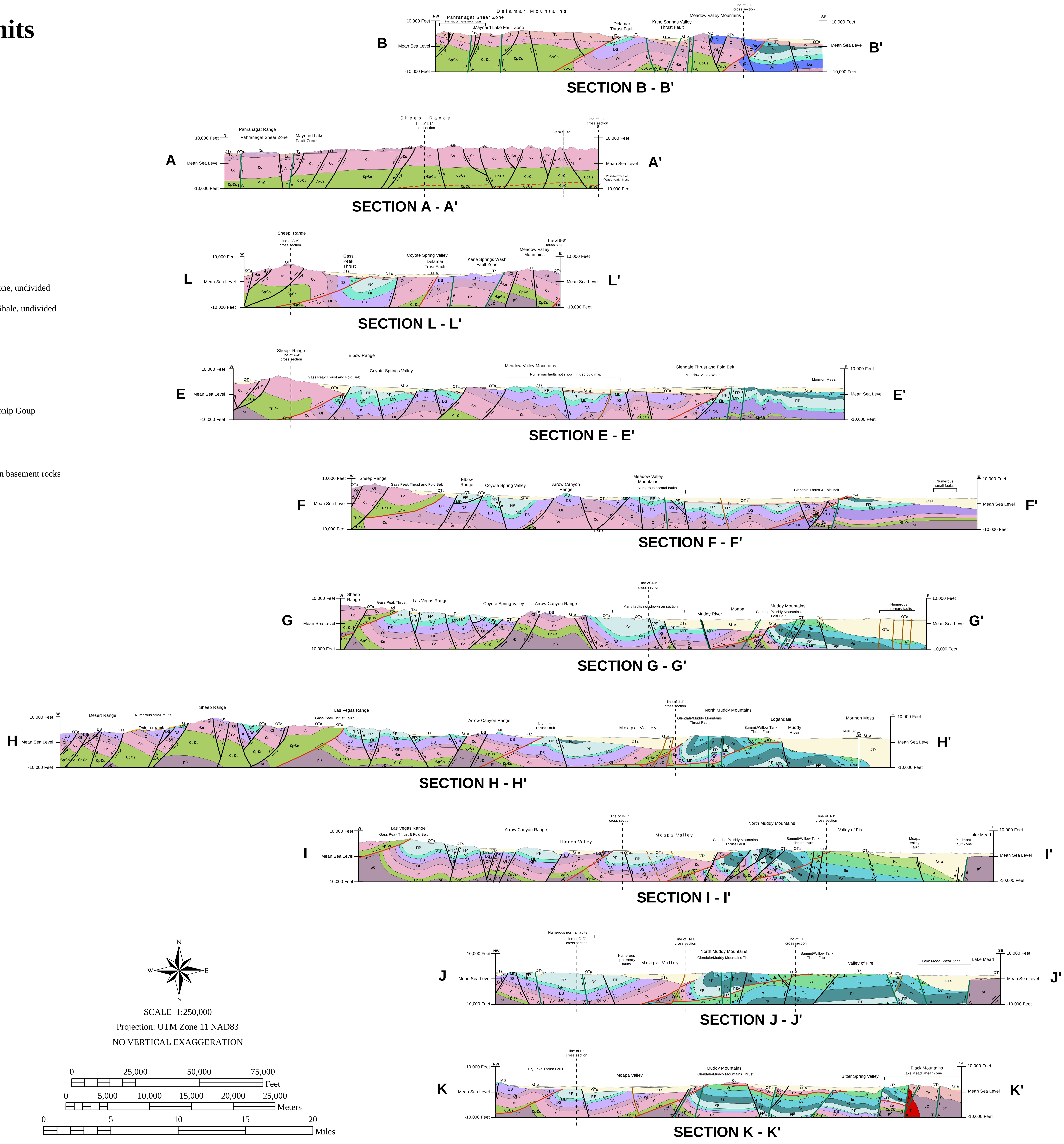
Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

Well Name
TD=1,234'
Oil Well Data Used in Cross Sections
TD = Total Depth (Feet)

SCALE 1:250,000
Projection: UTM Zone 11 NAD83
NO VERTICAL EXAGGERATION

0 25,000 50,000 75,000 Feet
0 5,000 10,000 15,000 20,000 25,000 Meters
0 5 10 15 20 Miles



SECTION B - B'
SECTION A - A'
SECTION L - L'
SECTION E - E'
SECTION F - F'
SECTION G - G'
SECTION H - H'
SECTION I - I'
SECTION J - J'
SECTION K - K'

SNWA Exhibit 58

SOUTHERN NEVADA WATER AUTHORITY

MAP ID 18434-3211 05/17/2011 BP

PLATE 5. CROSS SECTIONS SHOWING GEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA

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PLATE 6. HYDROGEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

MAP ID 18291-3211 06/02/2011 JAB/BP

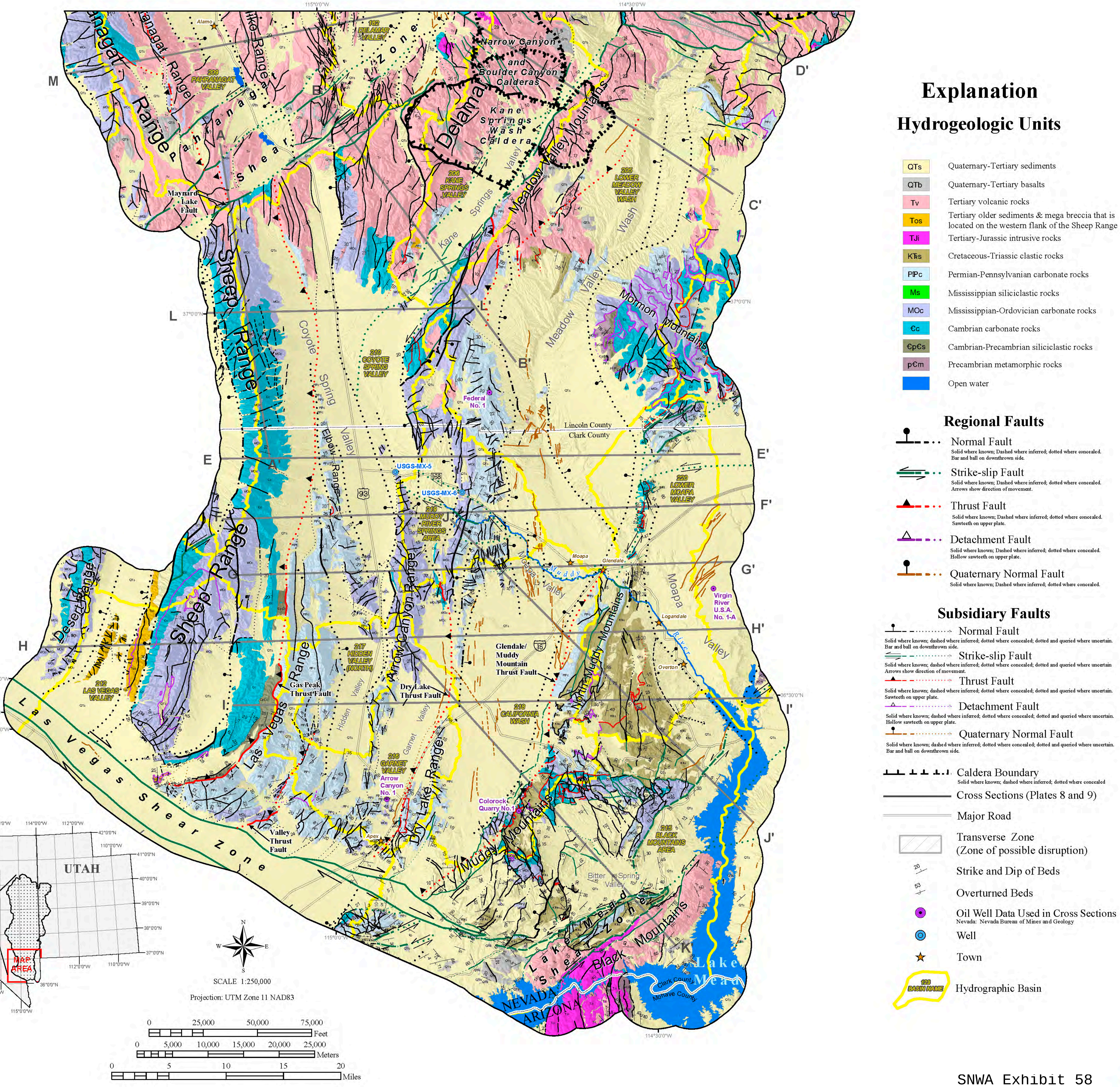

PLATE 7. HYDROGEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA, AND ADJACENT AREAS, ARIZONA

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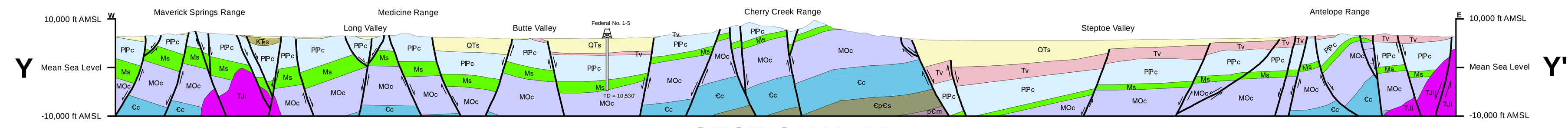
SOUTHERN NEVADA WATER AUTHORITY

MAP ID 18292-3211 06/02/2011 BP/JAB



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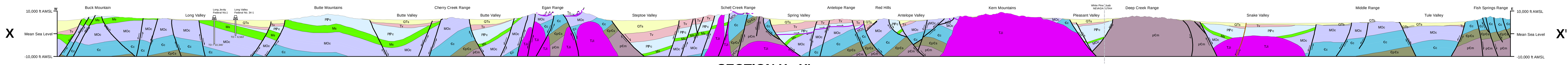

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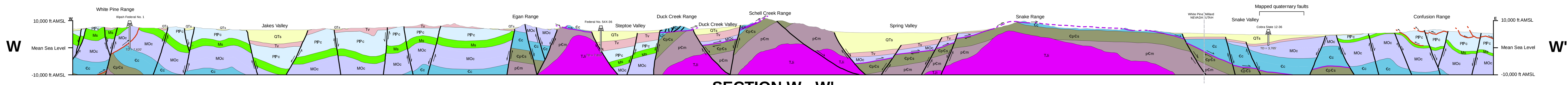

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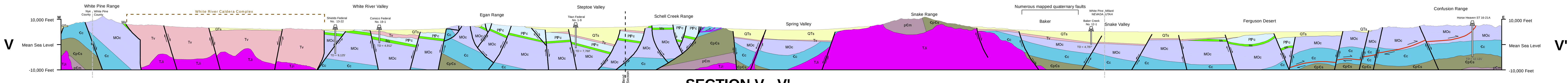

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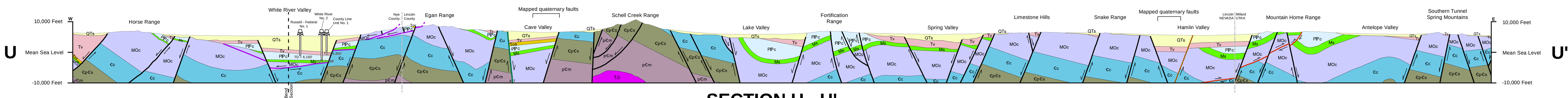

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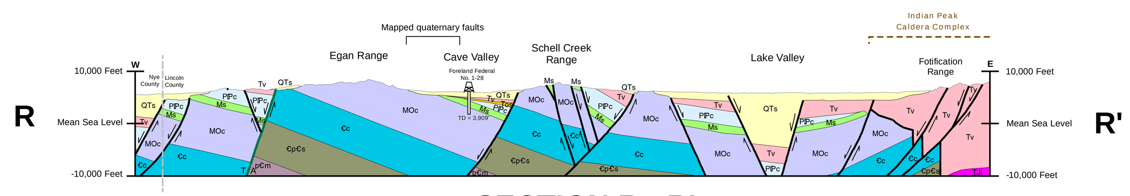

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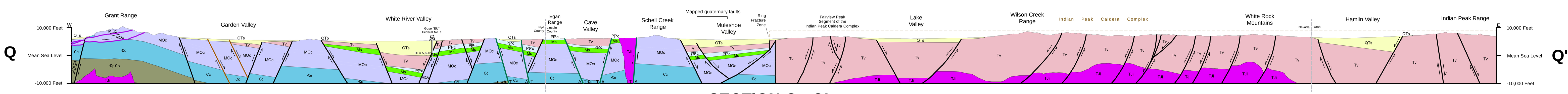

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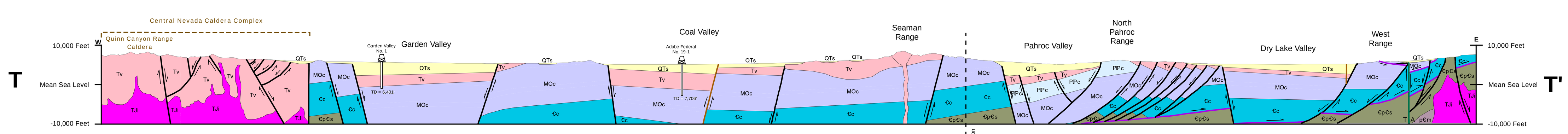

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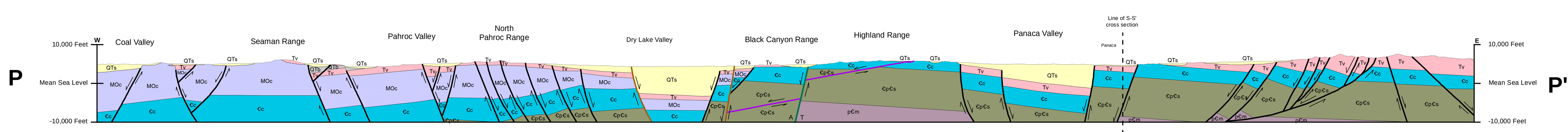

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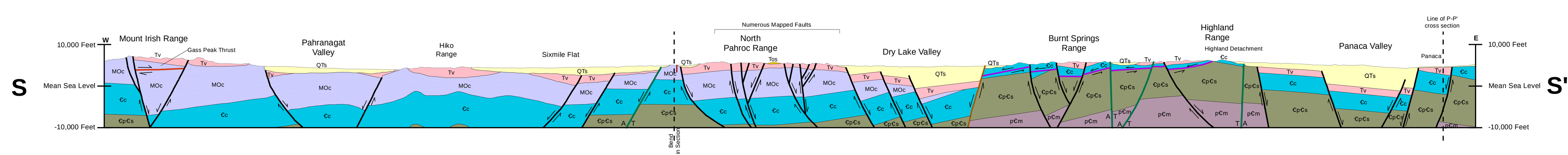

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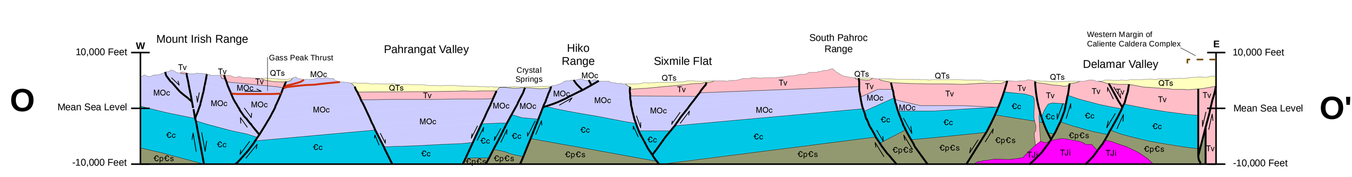

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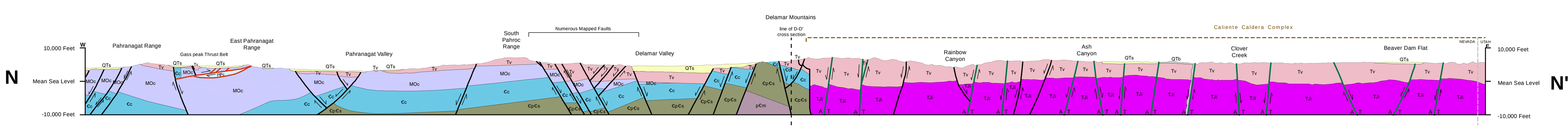

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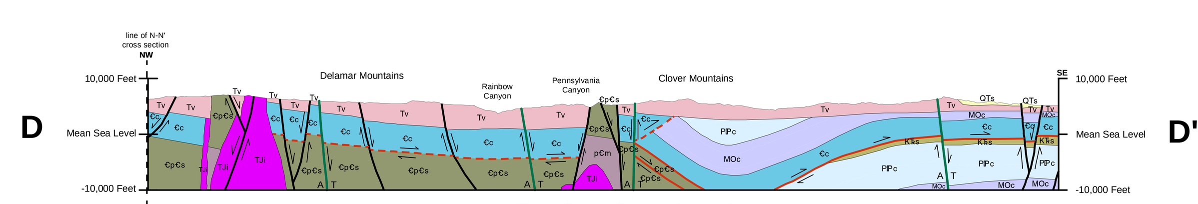

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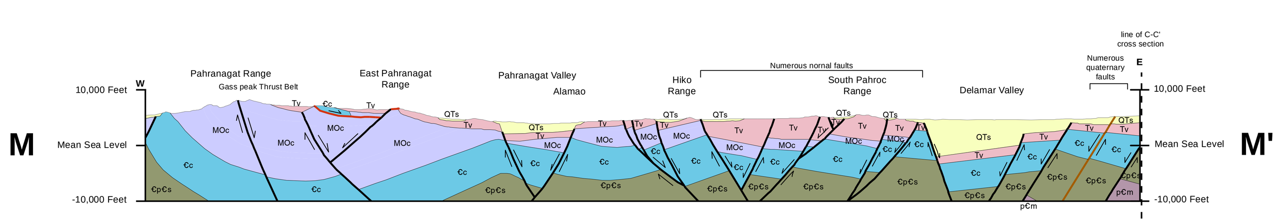
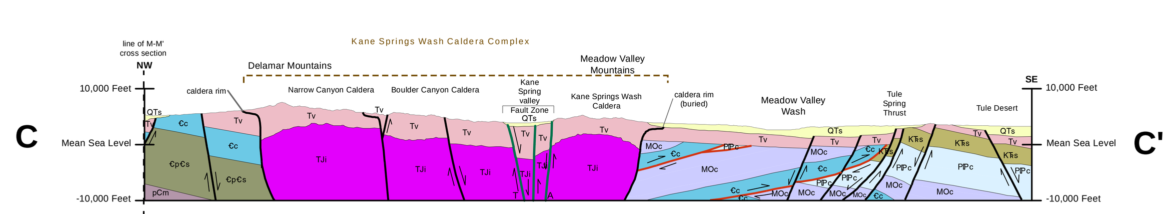


SECTION M - M'



SECTION C - C'

Explanation of Hydrogeologic Units

Shown on Cross Section

QTs	Quaternary-Tertiary sediments
QTb	Quaternary-Tertiary basalts
Tv	Tertiary volcanic rocks
Tos	Tertiary older sediments
TJi	Tertiary-Jurassic intrusive rocks
KTs	Cretaceous-Triassic clastic rocks
PPc	Permian-Pennsylvanian carbonate rocks
Ms	Mississippian siliciclastic rocks
MOc	Mississippian-Ordovician carbonate rocks
Cc	Cambrian carbonate rocks
CpCs	Cambrian-Precambrian siliciclastic rocks
pCm	Precambrian metamorphic rocks

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement. T= Towards, A = Away.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Well Name
TD=1,234'

Oil Well Data Used in Cross Sections
TD = Total Depth (Feet)

SCALE 1:250,000

Projection: UTM Zone 11 NAD83

0 25,000 50,000 75,000 100,000 Feet

0 7,000 14,000 21,000 28,000 35,000 Meters

0 5 10 15 20 25 Miles

SNWA Exhibit 58

SOUTHERN NEVADA WATER AUTHORITY

PLATE 8. CROSS SECTIONS SHOWING HYDROGEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

MAP ID 18435-3211 05/17/2011 BP

Explanation of Hydrogeologic Units
Shown on Cross Section

Symbol	Unit
QTs	Quaternary-Tertiary sediments
Tv	Tertiary volcanic rocks
TJi	Tertiary-Jurassic intrusive rocks
KTRs	Cretaceous-Triassic clastic rocks
PPc	Permian-Pennsylvanian carbonate rocks
MOc	Mississippian-Ordovician carbonate rocks
Cc	Cambrian carbonate rocks
CpCs	Cambrian-Precambrian siliciclastic rocks
pCm	Precambrian metamorphic rocks

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement. T= Towards, A = Away.

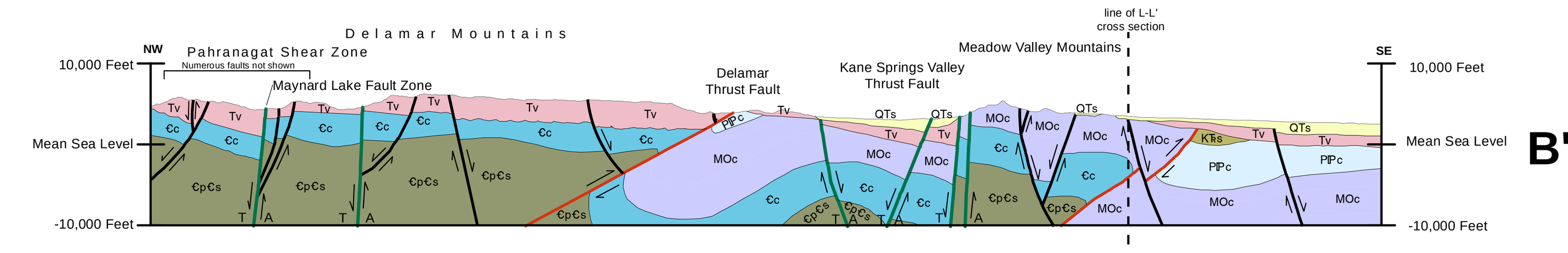
Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed.

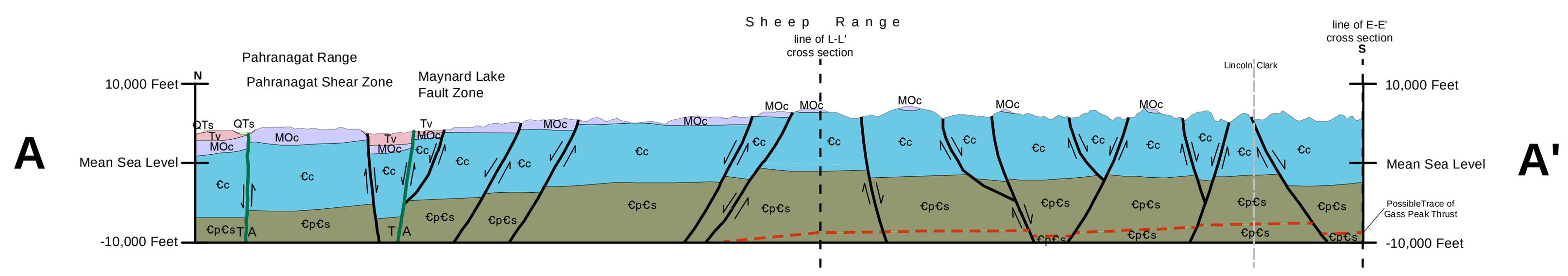
Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Well Name
TD=1,234'

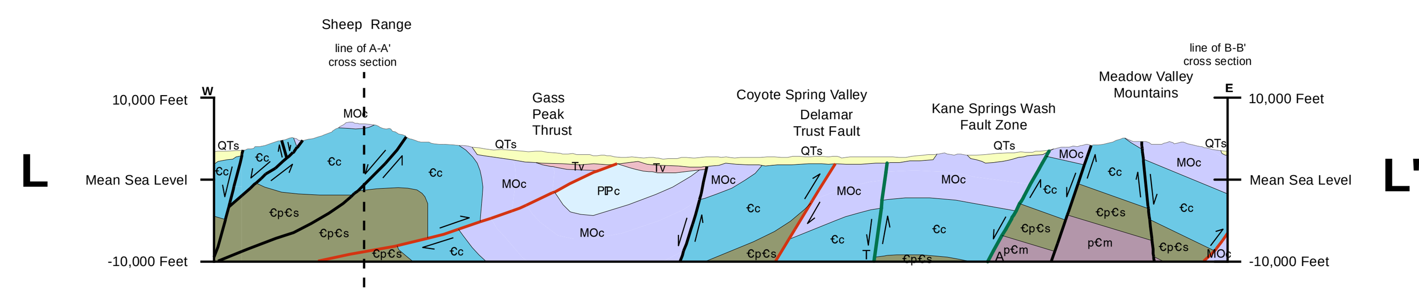
Oil Well Data Used in Cross Sections
TD = Total Depth (Feet)



SECTION B - B'



SECTION A - A'



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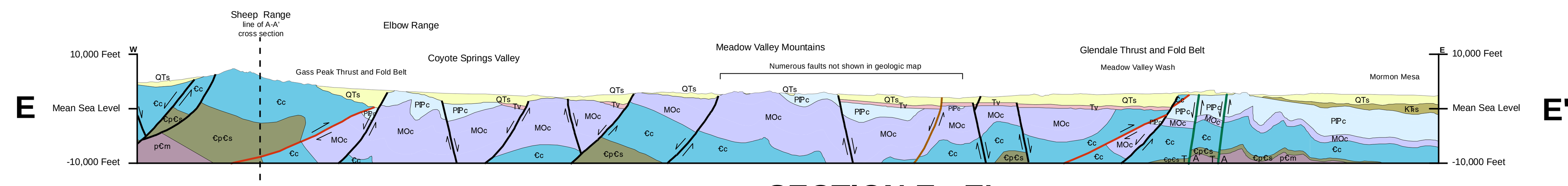

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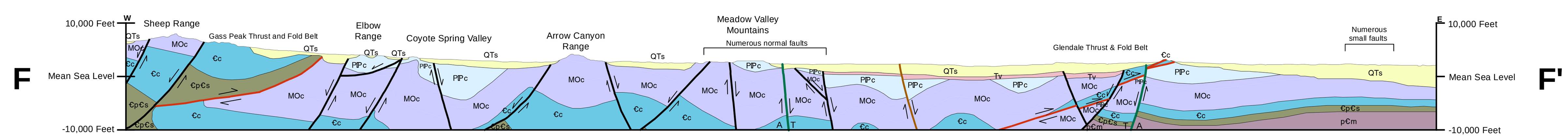

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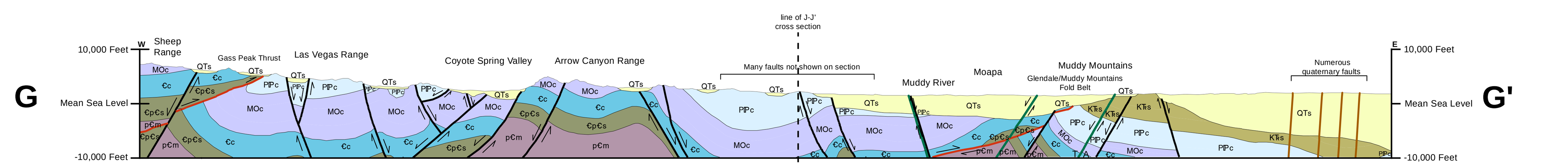

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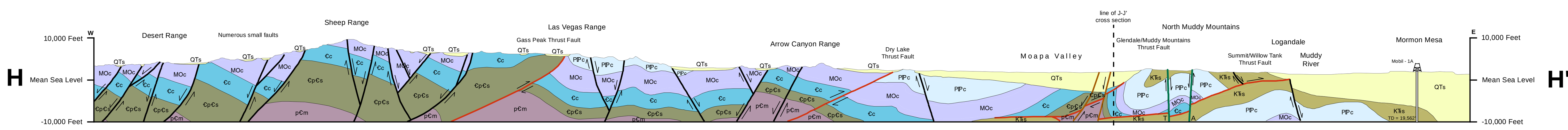
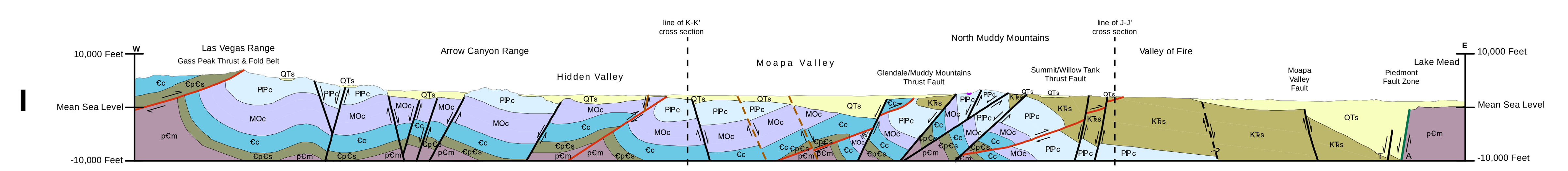
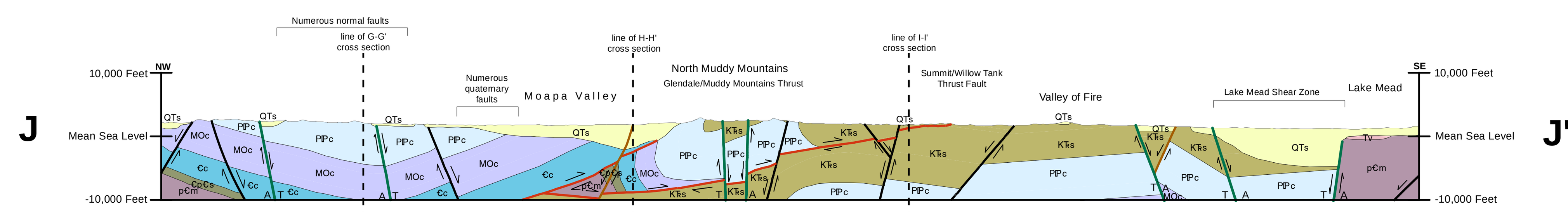


SECTION H - H'



SECTION I - I'



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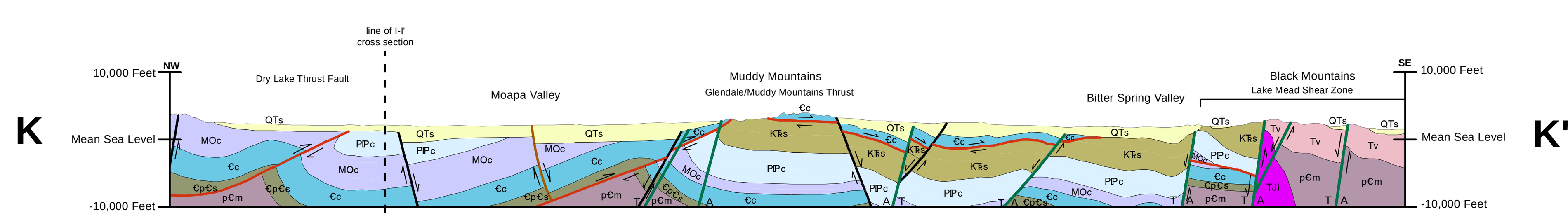
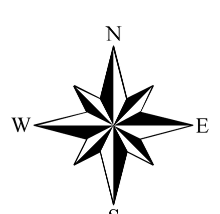


SECTION K - K'



SCALE 1:250,000

Projection: UTM Zone 11 NAD83

NO VERTICAL EXAGGERATION

0 25,000 50,000 75,000 Feet

0 5,000 10,000 15,000 20,000 25,000 Meters

0 5 10 15 20 Miles

SNWA Exhibit 58

SOUTHERN NEVADA WATER AUTHORITY

PLATE 9. CROSS SECTIONS SHOWING HYDROGEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA

MAP ID 18436-3211 05/17/2011 BP

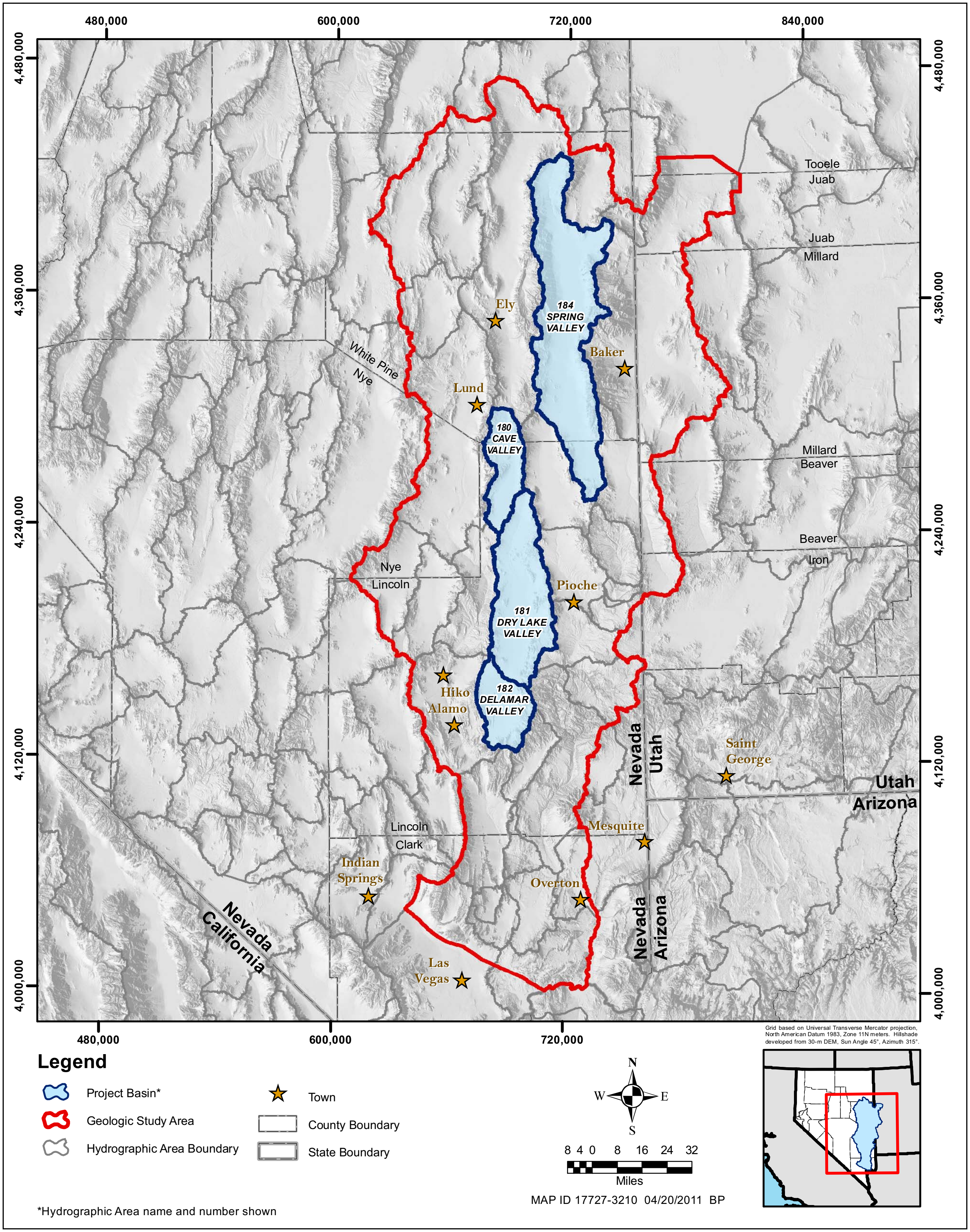
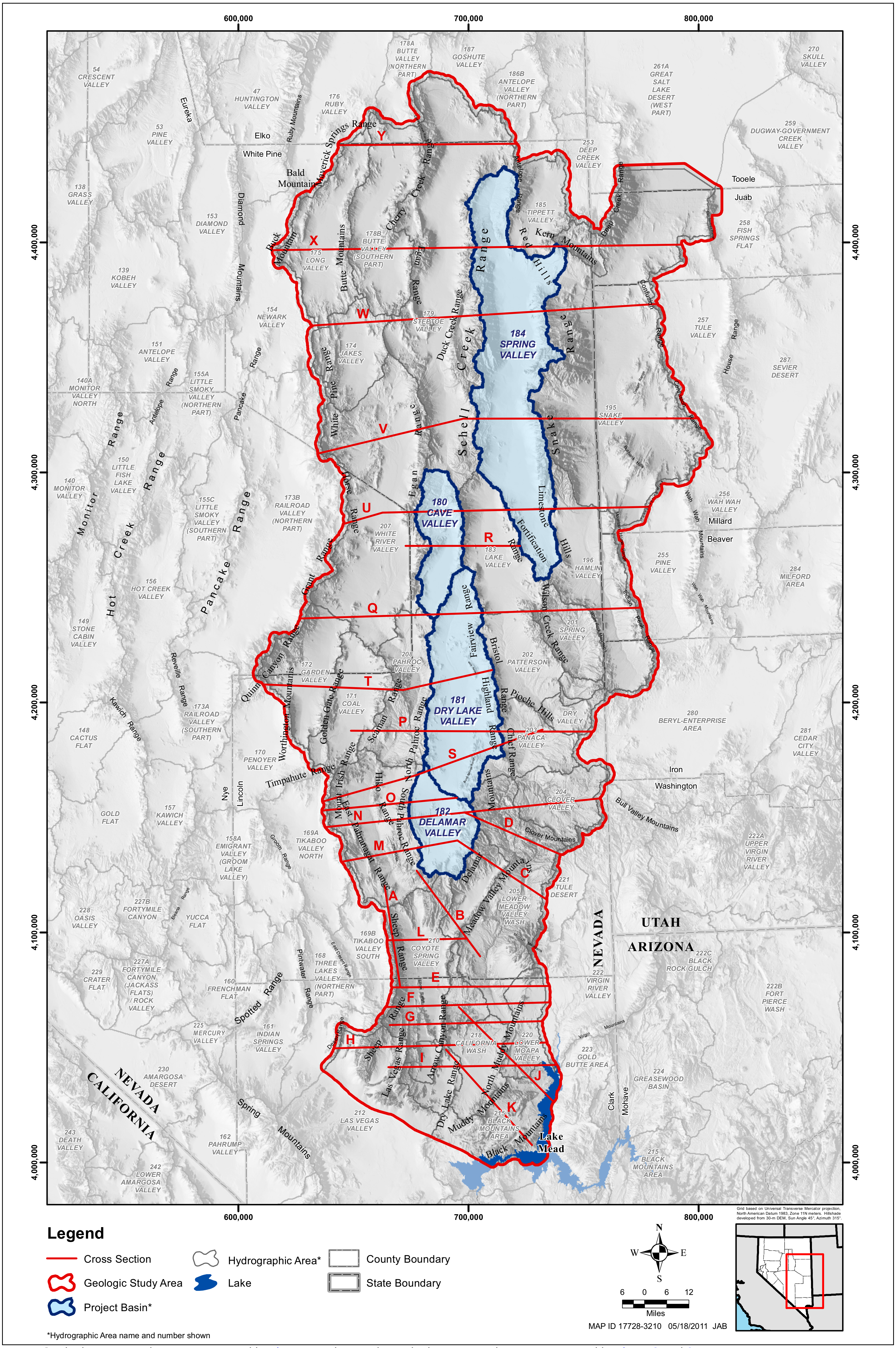
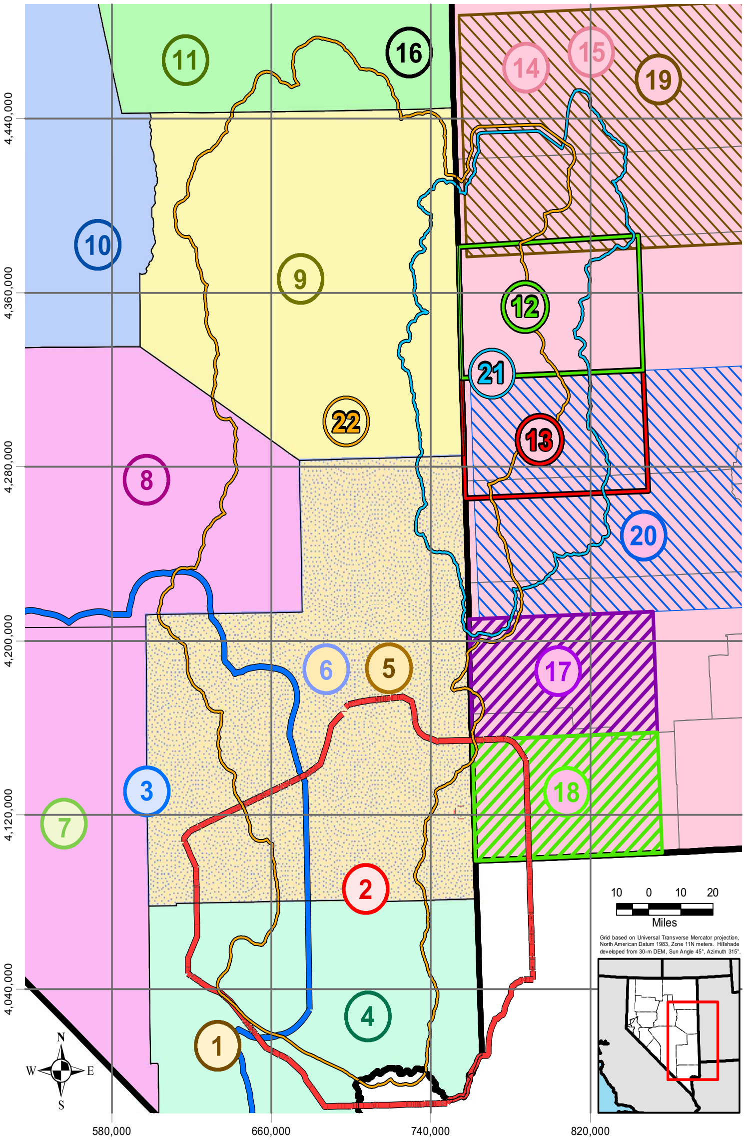


Figure 1-1
Location of Project Basins and Other Hydrographic Areas



Note: Geologic cross sections are presented in Plates 4 and 5. Hydrogeologic cross sections are presented in Plates 8 and 9.

Figure 2-1
Hydrographic Basins, Ranges, and Locations of Cross Sections



Source Maps:

1. Page, W.R., Lundstrom, S.C., Harris, A.G., Langenheim, V.E., Workman, J.B., Mahan, S.A., Paces, J.B., Dixon, G.L., Rowley, P.D., Burchfiel, B.C., Bell, J.W., and Smith, E.I., 2005, Geologic and Geophysical maps of the Las Vegas 30' × 60' quadrangle, Clark and Nye Counties, Nevada, and Inyo County, California: U.S. Geological Survey Scientific Investigations Map 2814, 55 p., scale 1:100,000.
2. Page, W.R., Dixon, G.L., Rowley, P.D., and Brickey, D.W., 2005, Geologic map of parts of the Colorado, White River, and Death Valley ground-water flow systems: Nevada Bureau of Mines & Geology Map 150, scale 1:250,000. Digital GIS data provided.
3. Workman, J.B., Menges, C.M., Page, W.R., Taylor, E.M., Ekren, E.B., Rowley, P.D., Dixon, G.L., Thompson, R.A., and Wright, L.A., 2002, Geologic map of the Death Valley ground water model area, Nevada and California: U.S. Geological Survey Miscellaneous Field Studies MF-2381-A, scale 1:250,000. Digital GIS data provided.
4. Longwell, C.R., Pampeyan, E.H., Bowyer, B., and Roberts, R.J., 1965, Geology and mineral deposits of Clark County, Nevada: Nevada Bureau of Mines and Geology Bulletin 62, 218 p., scale 1:250,000.
5. Tschanz, C.M., and Pampeyan, E.H., 1970, Geology and Mineral deposits of Lincoln County, Nevada: Nevada Bureau of Mines and Geology Bulletin 73, 187 p., scale 1:250,000.
6. Ekren, E.B., Orkild, P.P., Sargent, K.A., and Dixon, G.L., 1977, Geologic map of Tertiary rocks, Lincoln County, Nevada: U.S. Geological Survey Miscellaneous Investigations Series Map I-1041, scale 1:250,000.
7. Cornwall, H.R., 1972, Geology and mineral deposits of southern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 77, 49 p., scale 1:250,000.
8. Kleinhampl, F.J., and Ziony, J.I., 1985, Geology of northern Nye County, Nevada: Nevada Bureau of Mines and Geology Bulletin 99A, 172 p., scale 1:250,000.
9. Hose, R.K., and Blake, Jr., M.C., 1976, Geology and mineral resources of White Pine County, Nevada, Part 1, Geology: Nevada Bureau of Mines and Geology Bulletin 85, p. 1-35., scale 1:250,000.
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11. Coats, R.R., 1987, Geology of Elko County, Nevada: Nevada Bureau of Mines and Geology Bulletin 101, 112 p., scale 1:250,000.
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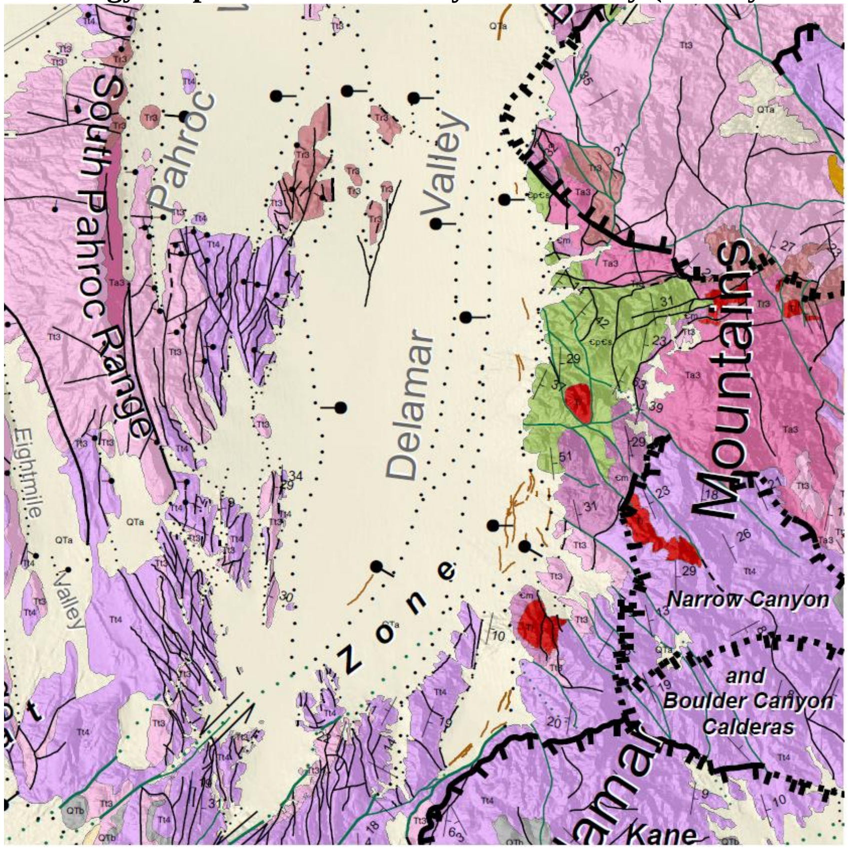
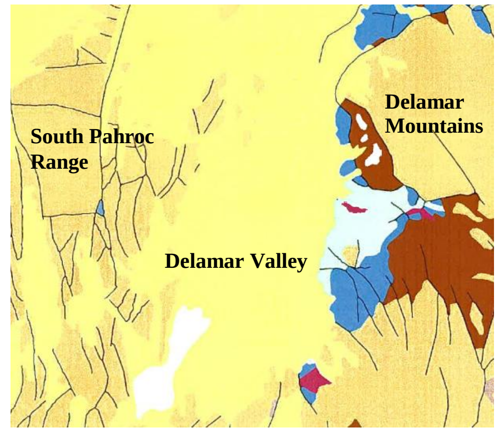
Figure 3-1
Previous Large-Scale Mapping Used to Evaluate Geology and to Create the Geologic and Hydrogeologic Maps of Plates 1 and 2

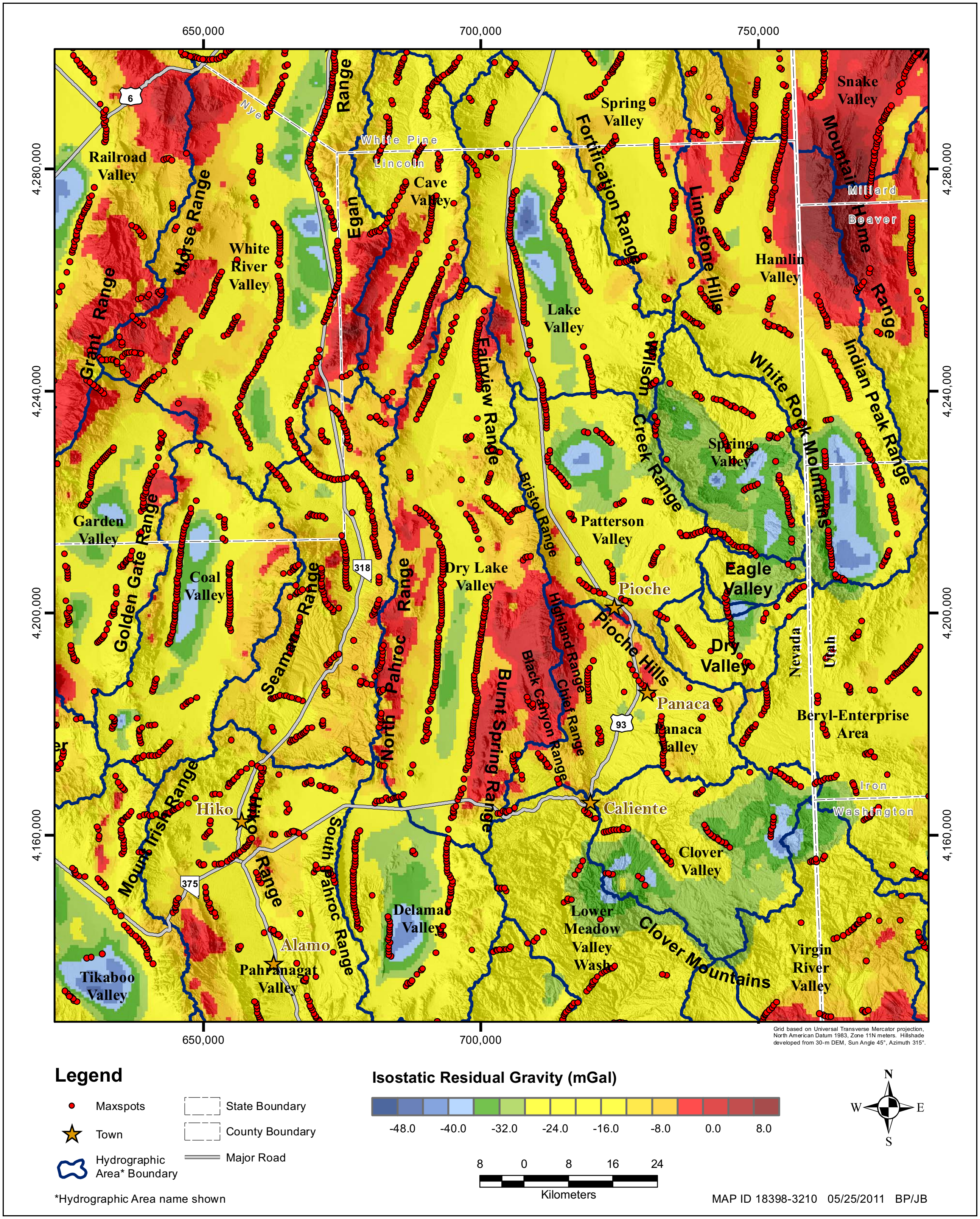
1:250,000 Geology Map of Delamar Valley and Vicinity (Rowley et al. 2011; Plate 1)



1:500,000 Geology Map of Delamar Valley and Vicinity (Stewart, J.H., and Carlson, J.E., 1978)



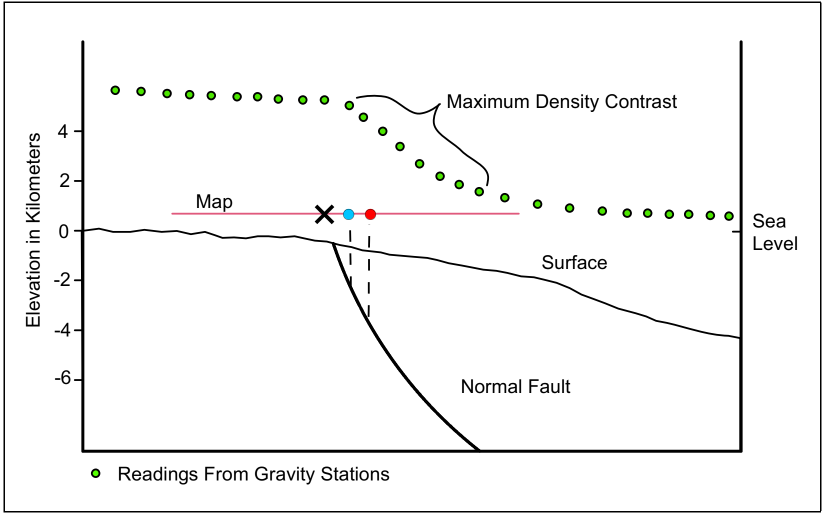
Shown above are examples of the same area of Nevada that were geologically mapped at two different scales (1:250,000 and 1:500,000). The Rowley et al. 2011 geology map was completed at a 1:250,000 scale and shows greater detail to the geologic structures and units. The 1:250,000 map illustrates interbasin structures (faults within the valley floor) and types of faults (i.e. black normal, brown quaternary, green lateral faults, and caldera boundaries), whereas the 1:500,000 map of Stewart, J.H., and Carlson, J.E., 1978 display fewer structures and does not distinguish the type of structure. The reason that the maps were completed at different scales is the 1:500,000 mapped the entire state of Nevada (which requires less detail), while the 1:250,000 scale map focused on the SNWA project area and provide greater detail to the geologic structures and units.



Source: Mankinen et al. (2008)

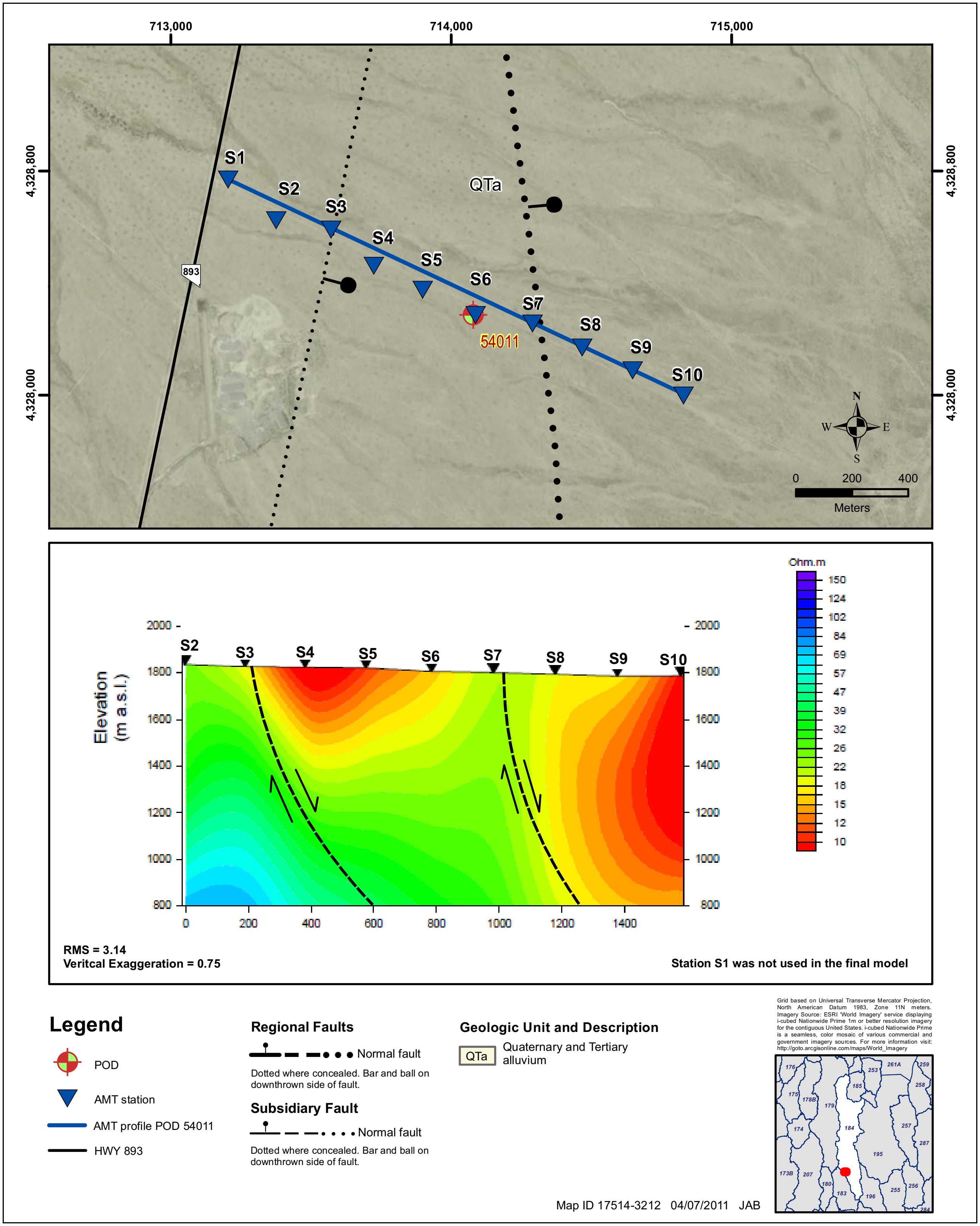
Figure 5-12
Isostatic Residual Gravity Field Showing Maxspots

SNWA Exhibit 58



Note: X at surface, blue dot from 2 km depth, red dot from 3 km depth.

Figure 5-1
Geologic Cross Section of a Normal Fault Interpreted from a Gravity Profile across It (Black Dots), Showing Upward-Continued Maxspots Projected onto a Map



Source: Pari and Baird (2011)

Figure 5-15
Map and 2D Model of Area of POD 54011

PLATE 1. GEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

Explanation

Geologic Units

- QTa — Quaternary and Tertiary basin-fill deposits
- QTb — Quaternary and Tertiary thin basalt flows and cinder cones
- Ts4 — Tertiary fluvial and lacustrine sediments
- Tt4 — Tertiary poorly-to-densely welded ash-flow tuff and interbedded airfall tuff
- Ta4 — Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
- Tr4 — Tertiary high-silica rhyolite lava flows and volcanic domes
- Ta3 — Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
- Tt3 — Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
- Tt2 — Tertiary poorly-densely welded ash-flow tuff and interbedded airfall tuff
- Ts1 — Tertiary fluvial and lacustrine sediments
- Tmb — Tertiary megabreccia
- Ti — Tertiary intrusive rocks
- Ks — Upper and Lower Cretaceous sedimentary rocks, undivided
- Js — Jurassic sedimentary rocks, undivided
- Ŧs — Triassic sedimentary rocks, undivided
- Pp — Upper and Lower Permian Park City Group, undivided
- Par — Permian Arcturus Formation and Rib Hill Sandstone
- PIP — Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone, undivided
- Md — Upper Mississippian Diamond Peak Formation
- Mc — Upper Mississippian Chainman Shale
- MD — Lower Mississippian to Upper Devonian Joana Limestone and Pilot Shale, undivided
- Ds — Middle and Lower Devonian Simonson and Sevy Dolomites
- Du — Devonian carbonate sedimentary rocks, undivided
- SOu — Silurian and Upper Ordovician dolomite, undivided
- Ol — Middle and Lower Ordovician, mostly Eureka Quartzite and the Pogonip Goup
- Єc — Cambrian carbonate sedimentary rocks, undivided
- Єu — Lower Ordovician? And Upper Cambrian limestone and shale, undivided
- Єm — Upper and Middle Cambrian limestone and shale
- ЄpЄs — Middle Cambrian to Late Proterozoic sedimentary rocks
- pЄ — Late to Early Proterozoic metamorphosed and crystalline Precambrian basement rocks
- Open Water

Regional Faults

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed. Bar and ball on downthrown side.

Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed. Sawteeth on upper plate.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed. Sawteeth on upper plate.

Quaternary Normal Fault
Solid where known; Dashed where inferred; dotted where concealed.

Subsidiary Faults

Normal Fault
Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Bar and ball on downthrown side.

Strike-slip Fault
Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Arrows show direction of movement.

Thrust Fault
Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Sawteeth on upper plate.

Detachment Fault
Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Hollow sawteeth on upper plate.

Quaternary Normal Fault
Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Bar and ball on downthrown side.

Caldera Boundary
Solid where known; Dashed where inferred; dotted where concealed

Cross Sections (Plates 4 and 5)

Major Road

Transverse Zone (Zone of possible disruption)

Town

Strike and Dip of Beds

Overturned Beds

Oil Well Data Used in Cross Sections
Nevada: Nevada Bureau of Mines and Geology

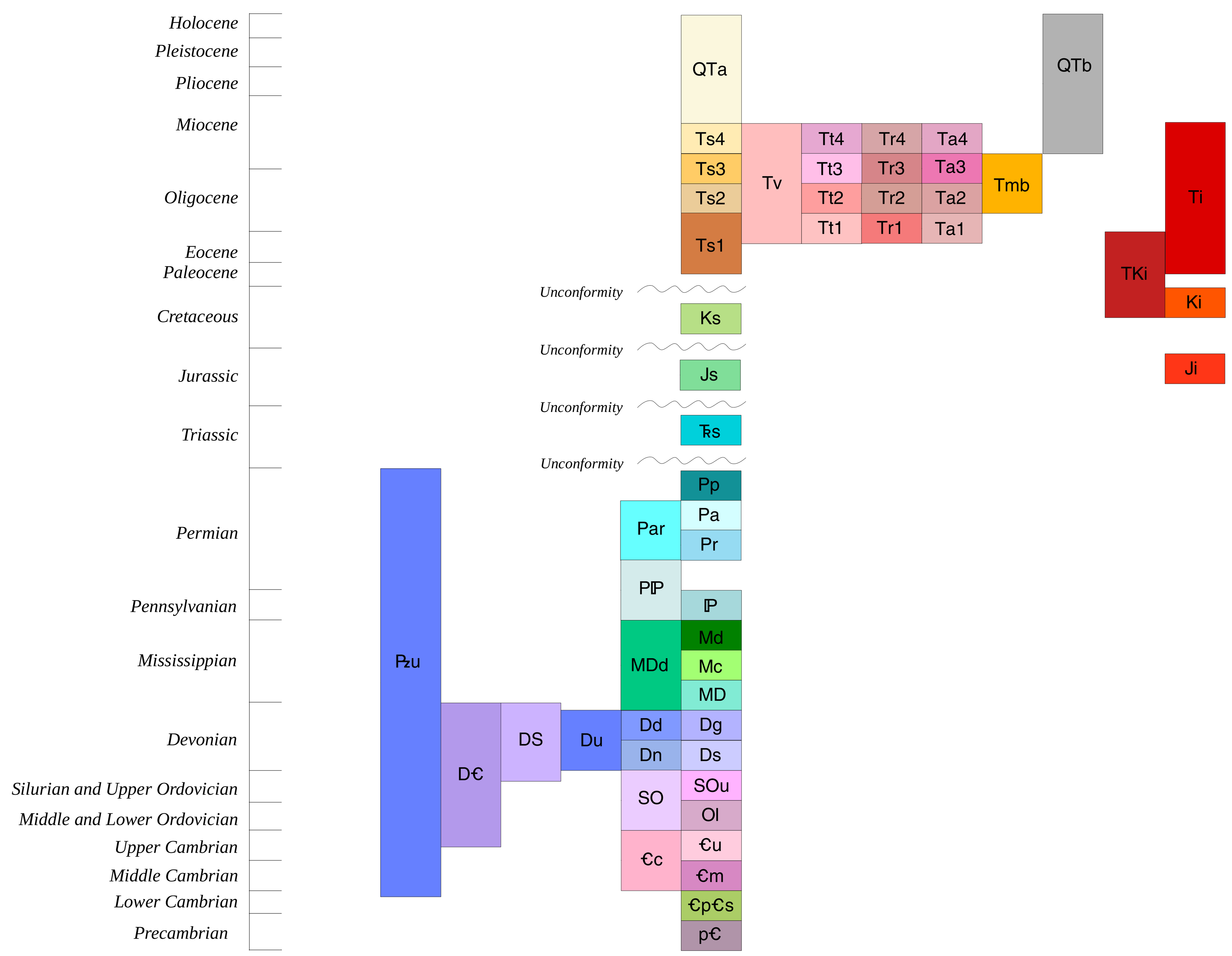
Well

SNWA Exhibit 58

SOUTHERN NEVADA WATER AUTHORITY

PLATE 2. GEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA , AND ADJACENT AREAS, ARIZONA

MAP ID 18287-3211 06/01/2011 BP/JAB



QTa Surficial and basin-fill deposits (Holocene to upper Miocene)—Unconsolidated to moderately consolidated, locally tuffaceous beds of sand, gravel, silt, and minor limestone deposited mostly by streams and small playa lakes. Generally thin but, where unit fills basin-range-fault-bounded basins, may be 0-5000 feet thick and forms the upper valley-fill aquifer. Some basin-fill deposits bear local names, including the Muddy Creek Formation (southern part of Plate 2), Panaca Formation (southern part of Plate 1), Horse Camp Formation (northwestern part of Plate 1), and Salt Lake Formation (northeastern part of Plate 1).

QTb Basalt lava flows (Holocene to lower Miocene)—Resistant, thin, basalt lava flows and cinder cones. The mafic end of the bimodal volcanic sequence that is synchronous with basin-range extensional faulting.

Ts4 Sedimentary rocks, unit 4 (Miocene)—Moderately to well consolidated, mostly fluvial sandstone, conglomerate, and minor lacustrine limestone. Primarily the Horse Spring Formation (11 to 20 Ma), a basal basin-fill sedimentary unit that is locally thick (3000+ feet) in the southern part of Plate 2.

Ts3 Sedimentary rocks, unit 3 (Miocene and Oligocene)—Moderately to well consolidated, thin, mostly fluvial, tuffaceous sandstone and bedded airfall tuff

Ts2 Sedimentary rocks, unit 2 (Oligocene)—Moderately to well consolidated, thin, mostly fluvial, tuffaceous sandstone and conglomerate. Includes the Gilmore Gulch Formation, with an age of about 30 Ma, in the northwestern part of Plate 1.

Ts1 Sedimentary rocks, unit 1 (Oligocene to Upper Cretaceous?)—Moderately to well consolidated, mostly fluvial sandstone, conglomerate, and minor lacustrine limestone. Primarily the Sheep Pass Formation, but in the central part of Plate 1, includes the Paleocene and Upper Cretaceous(?) Grapevine Wash Formation and the Eocene and Paleocene Claron Formation. Includes the Fowkes Formation and White Sage Formation in the northeastern part of Plate 1. Unit in most places underlies all volcanic rocks.

Tv Volcanic rocks (Miocene to Eocene)—Unit shown only in Plates 4, 5, 6, 7, 8, and 9, where it is referred to as the volcanic aquifer. May be several thousand feet thick in many places, and in calderas and near other source vents, may be many thousands of feet thick. On Plates 1 and 2, unit is separated into several rock types based on age, following the mapping strategy of Ekren et al, (1977).

Tt4 Ash-flow tuff and interbedded airfall tuff, unit 4 (Miocene)—Poorly to densely welded, bimodal high-silica rhyolite and locally peralkaline ash-flow tuff and related airfall tuffs. Includes the tuff of Honeycomb Rock (12.0 Ma), Ox Valley Tuff (14.0 Ma), tuff of Etna (14.0 Ma), tuff of Rainbow Canyon (15.6 Ma), tuff of Acklin Canyon (17.1 Ma), and tuff of Dow Mountain (17.4 Ma), derived from the Caliente caldera complex. Includes the Kane Wash Tuff (14.4 to 14.7 Ma), the tuff of Boulder Canyon (15.1 Ma), and the tuff of Narrow Canyon (15.8 Ma), derived from the Kane Springs Wash caldera complex.

Tt3 Ash-flow tuff and interbedded airfall tuff, unit 3 (Miocene and Oligocene)—Poorly to densely welded, calc-alkaline, low-silica rhyolite to dacite ash-flow tuff and related airfall tuffs. Includes the tuff of Teepee Rocks (17.8 Ma), Hiko Tuff (18.3 Ma), Racer Canyon Tuff (18.7 Ma), and both Bauers Tuff Member (22.8 Ma) and Swett Tuff Member (23.7 Ma) of the Condor Canyon Formation, all derived from the Caliente caldera complex. Also includes the Harmony Hills Tuff (22.0 Ma), probably derived from the eastern Bull Valley Mountains; the Leach Canyon Formation (23.8 Ma), probably derived from the Caliente caldera complex; the Bates Mountain Tuff (22.8 Ma), derived from Lander County, Nevada; and the tuff of Saulsbury Wash (21.6 Ma), the Pahranagat Formation (22.6 Ma), the tuff of White Blotch Spring (24 to 25 Ma), the tuff of Kiln Canyon (24.1 to 25.1 Ma), the tuff of Lunar Cuesta (24.6 Ma), the tuff of the Quinn Canyon Range, and the Shingle Pass Tuff (26.4), all derived from the central Nevada caldera complex; and the tuff of Bald Mountain (about 25 Ma), derived from the Bald Mountain caldera in the Groom Range.

Tt2 Ash-flow tuff and interbedded airfall tuff, unit 2 (Oligocene)—Poorly to densely welded, calc-alkaline, low-silica rhyolite to dacite and trachydacite ash-flow tuff and related airfall tuffs. Includes the Isom Formation (about 27 Ma), probably derived from the Indian Peak caldera complex; the outflow Monotony Tuff (27.3 Ma), the intracaldera tuff of Goblin Knobs (27.3 Ma), and the tuff of Hot Creek Canyon (30.0 Ma), all derived from the central Nevada caldera complex; the outflow Windous Butte Formation (31.4 Ma) and intracaldera tuff of Williams Ridge and Morey Peak (31.3 Ma), derived from the Williams Ridge caldera of the central Nevada caldera complex; and the Needles Range Group (29 to 32 Ma), derived from the Indian Peak caldera complex.

Tt1 Ash-flow tuff and interbedded airfall tuff, unit 1 (Oligocene and Eocene)—Poorly to densely welded, calc-alkaline, low-silica rhyolite to dacite and trachydacite ash-flow tuff and related airfall tuffs. Deposited in the northern part of Plate 1. Includes the Pancake Summit Tuff (33.7 Ma), derived from the Broken Back caldera west of Eureka; the Stone Cabin Formation (35.4 Ma), derived from an unknown caldera in or near northern Railroad Valley; and the Kalamazoo Tuff (35 Ma), derived from an unknown source probably in the northern Schell Creek Range or beneath adjacent northern Spring Valley. In Utah, includes the Tunnel Spring Tuff (35.4 Ma).

Tr4 Rhyolite lava flows, unit 4 (Miocene)—High-silica rhyolite lava flows and volcanic domes, mostly in and near the Caliente and Kane Springs Wash caldera complexes.

Tr3 Rhyolite lava flows, unit 3 (Miocene and Oligocene)—Low-silica rhyolite lava flows and volcanic domes, mostly in and near the Indian Peak, Caliente, and central Nevada caldera complexes.

Tr2 Rhyolite lava flows, unit 2 (Oligocene)—Low-silica rhyolite lava flows and volcanic domes, mostly in and near the central Nevada and Indian Peak caldera complexes.

Tr1 Rhyolite lava flows, unit 1 (Oligocene and Eocene)—Low-silica rhyolite lava flows and volcanic domes, exposed in the northern part of Plate 1.

Ta4 Intermediate-composition lava flows, unit 4 (Miocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Includes andesite of the Hamblin-Cleopatra volcano (11.5 to 14.2 Ma) in the Lake Mead area.

Ta3 Intermediate-composition lava flows, unit 3 (Miocene and Oligocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Includes andesite between the Racer Canyon Tuff and Condor Canyon Formation in the southeastern part of Plate 2, between the Caliente and Kane Springs Wash caldera complexes, and in and near the Indian Peak and central Nevada caldera complexes.

Ta2 Intermediate-composition lava flows, unit 2 (Oligocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Includes andesite in and near the Indian Peak caldera complex and in the southern Egan Range.

Ta1 Intermediate-composition lava flows, unit 1 (Oligocene and Eocene)—Andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia. Exposed in the northern part of Plate 1. In the northeastern part of Plate 1 includes thin ash-flow tuffs, notably the Kalamazoo tuff. In Utah, includes the Horn Silver Andesite.

Tmb Megabreccia (Miocene and Oligocene)—Masses of mostly Paleozoic sedimentary rocks and intertongued volcanic breccia deposited within calderas from landsliding of the oversteepened caldera margins following caldera subsidence as a result of rapid eruptions of ash-flow tuff. Includes rocks in the Indian Peak caldera complex, Caliente caldera complex and central Nevada caldera complex. Includes gravity slides west of the Sheep Range and Beaver Dam Mountains.

Ti Intrusive rocks (Miocene to Paleocene)—Mostly silicic, calc-alkaline plutons.

TKi Intrusive rocks (Miocene to Cretaceous)—Mostly silicic, calc-alkaline plutons.

Ki Intrusive rocks (Upper Cretaceous)—Mostly silicic, calc-alkaline plutons that accompanied Sevier deformation.

Ks Sedimentary rocks, undivided (Upper and Lower Cretaceous)—Sevier-age, mostly thin, fluvial synorogenic clastic deposits, including the Baseline Sandstone (Upper and Lower Cretaceous) and Willow Tank Formation (Upper Cretaceous) in the southern part of Plate 2, and the Iron Springs Formation (Upper Cretaceous), Cedar Mountain Formation (Upper Cretaceous), and Dakota Sandstone (Upper Cretaceous) in the southeastern part of Plate 2; and the Newark Canyon Formation (Paleocene? to Lower Cretaceous?) in the northern part of Plate 1.

Ji Intrusive rocks (Jurassic)—Mostly silicic, calc-alkaline plutons that accompanied Sevier deformation.

Js Sedimentary rocks, undivided (Jurassic)—Includes, in the southeastern part of Plate 2, the mostly marine Carmel and underlying Temple Cap formations (Middle Jurassic). Also in the southeastern part of Plate 2, includes the eolian Navajo Sandstone and mostly fluvial Kayenta and Moenave formations, all Lower Jurassic. Mostly clastic units. In the southern part of Plate 2, the Aztec Sandstone is the equivalent of the Navajo. Includes the Dunlop Formation (Lower Jurassic) in the northwestern part of Plate 1.

TRs Sedimentary rocks, undivided (Triassic)—Includes, in the southeastern part of Plate 2, the mostly fluvial Chinle Formation (Upper Triassic) and mostly fluvial Moenkopi Formation (Middle? and Lower Triassic). Includes the Luning Formation (Upper Triassic) in the northern part of Plate 1. In the northeastern part of Plate 1, includes the Thaynes Formation (Lower Triassic). The majority of these rocks are clastic.

Pzu Paleozoic sedimentary rocks, undivided—Shown on Plates 4, 5, 8, and 9, where rocks in the hanging wall of the Snake Range decollement are buried by younger rocks.

Pp Park City Group, undivided (Upper and Lower Permian)—From top to base, consists of the Gerster Limestone (Upper Permian), Plympton Formation (Upper and Lower Permian), Kaibab Limestone (Lower Permian), and Toroweap Formation (Lower Permian). These make up the top of the upper carbonate aquifer.

Par Arcturus Formation and Rib Hill Sandstone, undivided (Lower Permian)—Included within the upper carbonate aquifer. Includes the Pequop Formation in Elko County, a redbed unit in the southern part of Plate 2, and the Queantoweap Sandstone in the southeastern part of Plate 2.

Pa Arcturus Formation (Lower Permian)—Predominantly carbonate rocks in the northern part of Plate 1, thickening eastward.

Pr Rib Hill Sandstone (Lower Permian)—Only in the northwestern part of Plate 1.

Pℙ Riepe Spring Limestone and Ely Limestone, undivided (Lower Permian and Pennsylvanian)— Mapped only in the northern part of Plate 1. The Riepe Spring Limestone (Lower Permian) is exposed in the northwestern part of Plate 1. Includes the Brock Canyon Formation (Permian and/or Pennsylvanian) in the northwestern part of Plate 1; the Oquirrh Group (Lower Permian and Pennsylvanian) in the northeastern part of Plate 1; and the Bird Spring Formation (Lower Permian to Upper Mississippian) in Clark County, Nevada and the Pakoon Formation (Lower Permian) in Utah.

ℙ Ely Limestone (Pennsylvanian)—May include Missippian rocks at its base. Mapped mostly in the central and northern part of Plate 1, thickening eastward. Includes the Wildcat Peak Formation in the northwestern part of Plate 1 and the Callville Limestone in the southern and eastern part of Plate 2.

MDd Diamond Peak Formation, Chainman Shale, Joana Limestone, and Pilot Shale, undivided (Upper Mississippian to Upper Devonian)

Md Diamond Peak Formation (Upper Mississippian)—Only in the northwestern part of Plate 1. This is a clastic unit derived from erosion of the Antler highland, including the Roberts Mountain thrust formed during the Antler deformational event. Includes the Scotty Wash Quartzite in the southwestern part of Plate 2.

Mc Chainman Shale (Upper Mississippian)—A clastic confining unit that has a similar origin to the Diamond Peak Formation. The two make up the upper aquitard in the northern half of Plate 1. Thus for this part of the map area, it separates the upper from the lower carbonate aquifer; in the area of Plate 2, the Chainman is thin and does not constitute a significant regional aquitard.

MD Joana Limestone and Pilot Shale, undivided (Lower Mississippian to Upper Devonian)—The Joana Limestone (Lower Mississippian) and Pilot Shale (Lower Mississippian and Upper Devonian) make up the top of the lower carbonate aquifer in the northern half of Plate 1. Includes local Lower Mississippian units Mercury Limestone and Bristol Pass Limestone. Includes the Rogers Spring Limestone (Lower Mississippian) and Monte Cristo Limestone (Upper and Lower Mississippian) in the southern part of Plate 2; the Eleana Formation (Mississippian and Upper Devonian) in the western part of Plate 2; the Webb Formation (Lower Mississippian) in Elko County ; the Ochre Mountain Limestone and underlying Woodman Formation (Lower Mississippian) in the eastern part of Plate 1; and the West Range Limestone (Upper Devonian) in northern Lincoln County. May include, at the top, thin deposits of the Chainman Shale.

D€ Devonian to Upper Cambrian carbonate and clastic rocks, undivided.

DS Devonian and Silurian sedimentary rocks, undivided—Only shown on some cross sections (Plates 4, 5, 8, and 9).

Du Devonian carbonate sedimentary rocks, undivided—Includes the Woodruff Formation (Upper and Middle Devonian) in Elko County; and the Muddy Peak Limestone (Upper and Middle? Devonian) in the southern part of Plate 2.

Dd Devils Gate Formation (Upper and Middle Devonian)—The western equivalent of the Guilmette Formation.

Dg Guilmette Formation (Upper and Middle Devonian)—Mapped throughout, except in the western part of Plate 1. Includes the Sultan Limestone in Clark County.

Dn Nevada Formation (Middle and Lower Devonian)—The western equivalent of the Simonson and Sevy Dolomites. Includes the Cockalorum Wash Formation, also in the western part of Plate 1.

Ds Simonson Dolomite (Middle and Lower Devonian) and Sevy Dolomite, undivided (Lower Devonian)—Mapped in all but the western part of Plate 1.

SO Silurian and Ordovician sedimentary rocks, undivided—Shown on some cross sections (Plates 4, 5, 8, and 9).

SOu Upper part (Silurian and Upper Ordovician)--Includes the Laketown Dolomite (Silurian), Fish Haven Dolomite (Upper Ordovician), Ely Springs Dolomite (Upper Ordovician), and Hanson Creek Formation (Upper Ordovician). Includes the Roberts Mountains Formation and the Lone Mountain Dolomite in the northwestern part of Plate 1.

Ol Lower part (Middle and Lower Ordovician)—Mostly the Eureka Quartzite (Middle Ordovician) and the Pogonip Group (Middle and Lower Ordovician). Includes the Vinini Formation and Valmy Formation in the northwestern part of Plate 1. Includes the Ely Springs Dolomite where it is thin in Clark County. In Utah, includes the Crystal Peak, Watson Ranch, and Fillmore formations and the House Limestone.

€c Cambrian carbonate sedimentary rocks, undivided—Shown only on some cross sections (Plates 4, 5, 8, and 9).

€u Upper part (Lower Ordovician? and Upper Cambrian)—Includes the Notch Peak Limestone, Orr Formation, Windfall Formation, Nopah Limestone, Dunderberg Shale, and Corset Spring Shale. In the extreme southwestern part of Plate 2, includes the Emigrant Formation (Upper and Middle Cambrian).

€m Middle part (Upper and Middle Cambrian)—Mostly the Highland Peak Formation and its southwestern equivalent, the Bonanza King Formation. In Nevada, includes local units known as the Pole Canyon Limestone, Lincoln Peak Formation, Patterson Pass Shale, Hamburg Formation, Secret Canyon Shale, Geddes Limestone, and Eldorado Formation. Includes the Muav Limestone in eastern Clark County. In Utah, includes the Wah Wah Summit, Trippe, Pierson Cove, Eye of Needle, Swasey, Whirlwind, Dome, Chisholm, and Howell formations. This unit is a thick limestone sequence that marks the base of the lower carbonate aquifer.

€p€s Lower part (Middle Cambrian to Late Proterozoic)—Chisholm Shale (Middle Cambrian), Lyndon Limestone (Middle Cambrian), Pioche Shale (Middle and Lower Cambrian), Carrara Formation (Middle and Lower Cambrian), Stella Lake Quartzite (Lower Cambrian), Prospect Mountain Quartzite (Lower Cambrian and Late Proterozoic), and Johnnie Formation (Late Proterozoic). The Prospect Mountain, in turn, has been subdivided into the Zabriskie Quartzite (Lower Cambrian), Wood Canyon Formation (Lower Cambrian), and Sterling Quartzite (Lower Cambrian and Late Proterozoic). Locally includes the Reed Dolomite (Lower Cambrian) and underlying Wyman Formation (Lower Cambrian?) in the southwestern part of Plate 2.

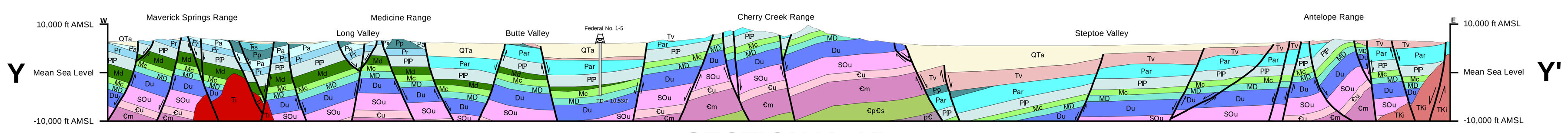
p€ Metamorphosed and crystalline Precambrian basement rocks (Late to Early Proterozoic)—Throughout most of Plates 1 and 2, consists of metamorphosed quartzite of Late Proterozoic age, namely the McCoy Creek Group and, in Utah, also the underlying Trout Creek Group. Locally, in the southern part of Plate 2, includes crystalline basement rocks.

Open Water

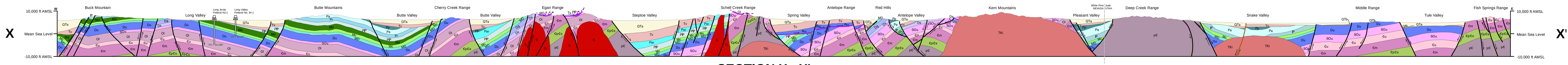
PLATE 3. EXPLANATION OF GEOLOGIC UNITS FOR THE MAPS AND CROSS SECTIONS OF PLATES 1, 2, 4, AND 5.

SNWA Exhibit 58

MAP ID 18288-3211 04/20/2011 BP



SECTION Y - Y'



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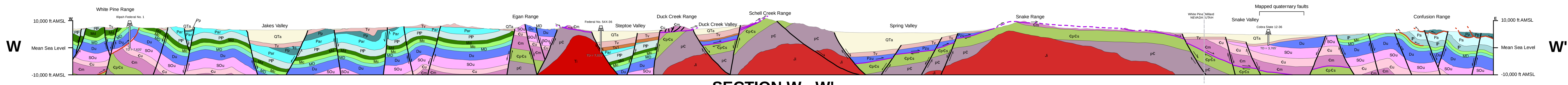

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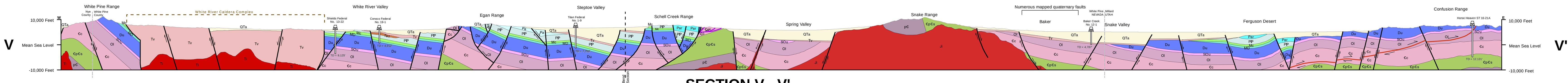

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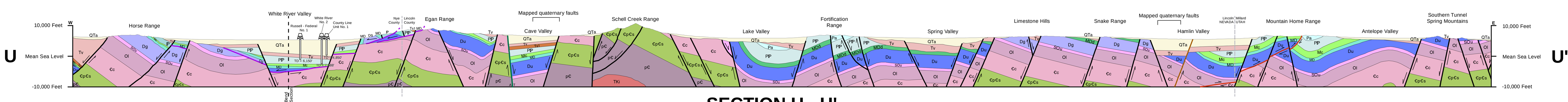

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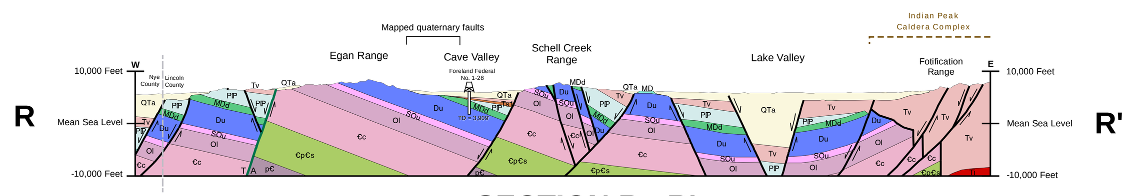

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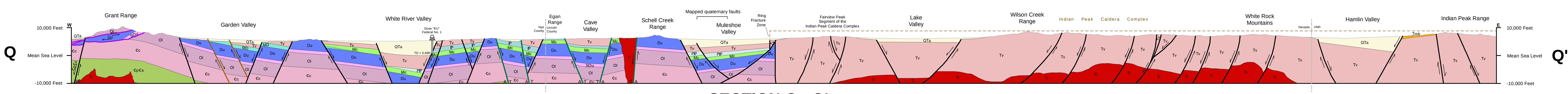

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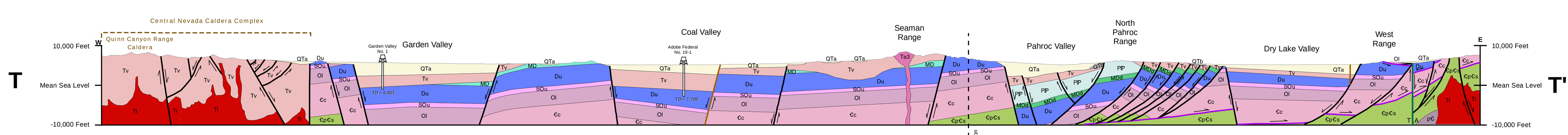

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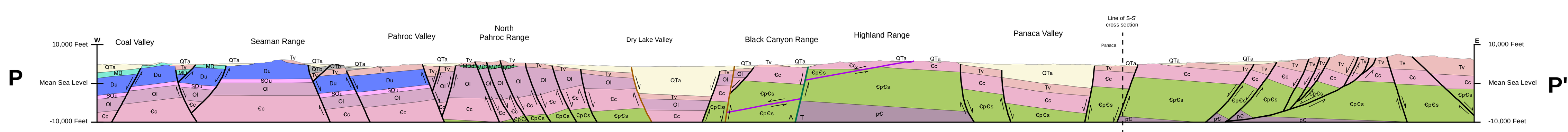

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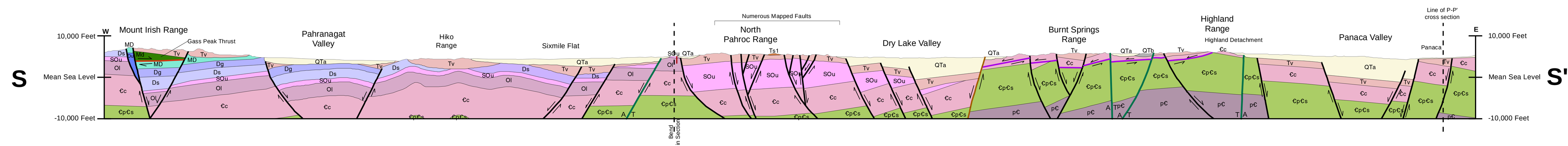

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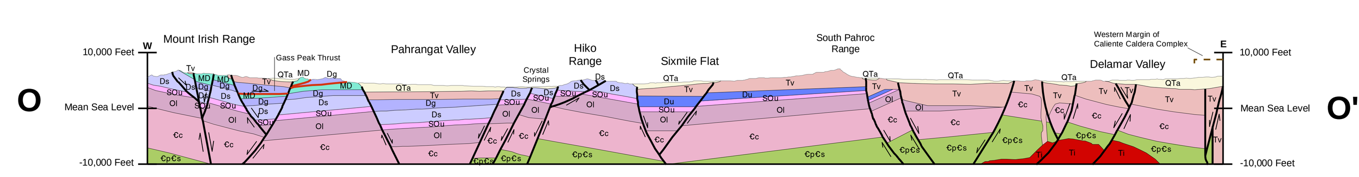
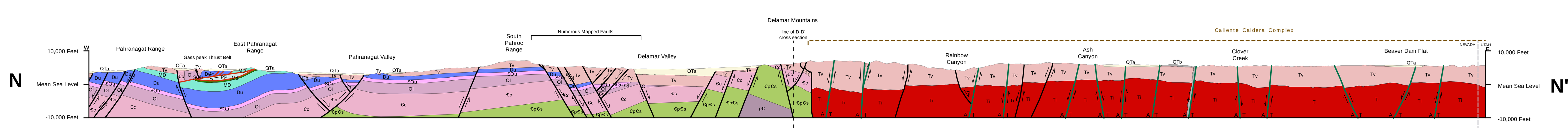


SECTION O - O'



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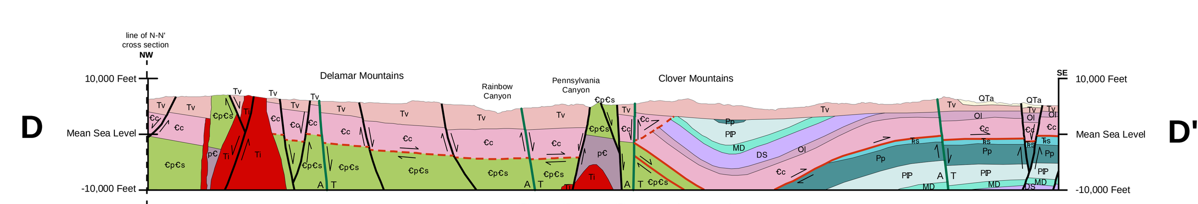

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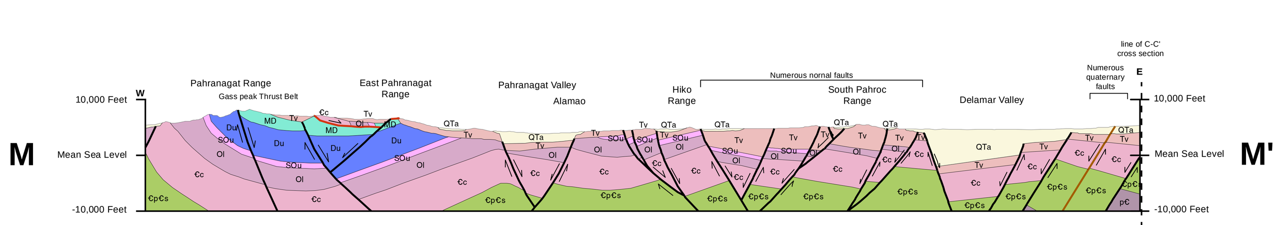

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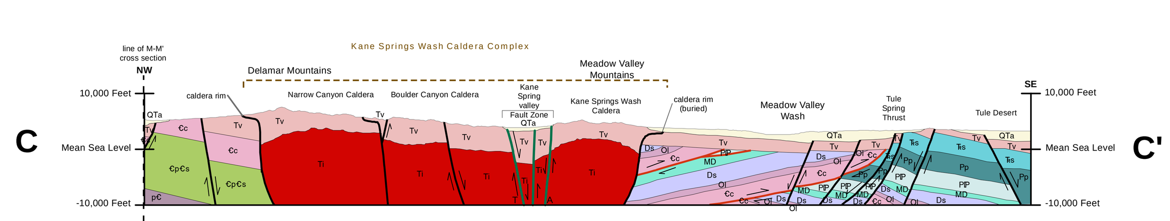


SECTION C - C'

Explanation of Geologic Units

Shown on Cross Section

QTa	Quaternary and Tertiary basin-fill deposits
QTb	Quaternary and Tertiary thin basalt flows and cinder cones
Tv	Tertiary volcanic ash-flows, flows and ash-fall tuffs
Ta3	Tertiary andesitic and locally dacitic lava flows, flow breccia, and mudflow breccia
Ts1	Tertiary fluvial and lacustrine sediments
Tmb	Tertiary intracaldera megabreccia
Ti	Tertiary intrusive rocks
TKi	Tertiary-Cretaceous intrusive rocks
Ki	Cretaceous intrusive rocks
Ks	Upper and Lower Cretaceous sedimentary rocks, undivided
Ji	Jurassic intrusive rocks
Js	Jurassic sedimentary rocks, undivided
₸s	Triassic sedimentary rocks, undivided
Pzu	Paleozoic Rocks, Undifferentiated
Pp	Upper and Lower Permian Park City Group, undivided
Par	Permian Arcturus Formation and Rib Hill Sandstone
Pa	Permian Arcturus Formation
Pr	Lower Permian Rib Hill Sandstone
PIP	Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone, undivided
IP	Pennsylvanian Ely Limestone
MDd	Upper Mississippian to Upper Devonian Diamond Peak Formation, Chainman Shale, Joana Limestone, and Pilot Shale, undivided
Md	Upper Mississippian Diamond Peak Formation
Mc	Upper Mississippian Chainman Shale
MD	Lower Mississippian to Upper Devonian Joana Limestone and Pilot Shale, undivided
DS	Devonian and Silurian sedimentary rocks, undivided
Du	Devonian carbonate sedimentary rocks, undivided
Dd	Upper and Middle Devonian Devils Gate Formation
Dg	Upper and Middle Devonian Guilmette Formation
Dn	Middle and Lower Devonian Nevada Formation
Ds	Middle and Lower Devonian Simonson and Sevy Dolomites
SOu	Silurian and Upper Ordovician dolomite, undivided
Ol	Middle and Lower Ordovician, mostly Eureka Quartzite and the Pogonip Goup
€c	Cambrian carbonate sedimentary rocks, undivided
€u	Lower Ordovician? And Upper Cambrian limestone and shale, undivided
€m	Upper and Middle Cambrian limestone and shale
€p€s	Middle Cambrian to Late Proterozoic sedimentary rocks
p€	Late to Early Proterozoic metamorphosed and crystalline Precambrian basement rocks

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

Strike-slip Fault (T / A)
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement. T= Towards, A = Away.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

Well Name
TD=1,234'

Oil Well Data Used in Cross Sections
TD = Total Depth (Feet)

N E S W

SCALE 1:250,000

Projection: UTM Zone 11 NAD83

0 25,000 50,000 75,000 100,000 Feet

0 7,000 14,000 21,000 28,000 35,000 Meters

0 5 10 15 20 25 Miles

SNWA Exhibit 58

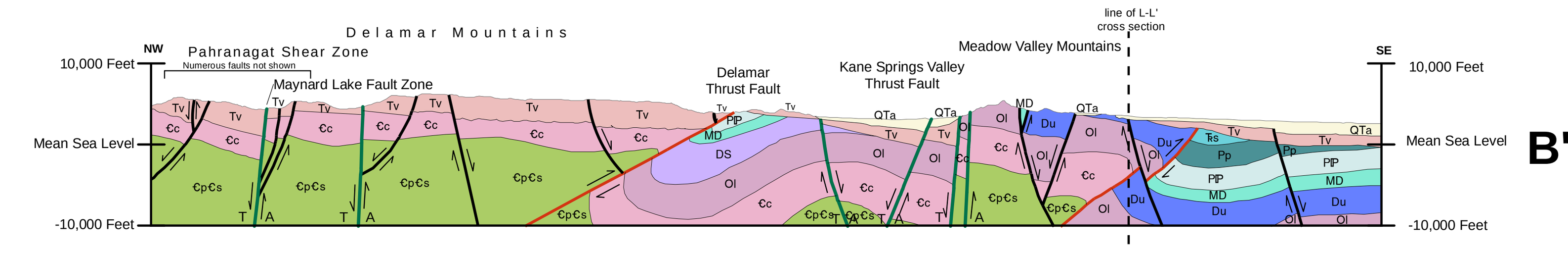
SOUTHERN NEVADA WATER AUTHORITY

MAP ID 18433-3211 05/25/2011 JAB/BP

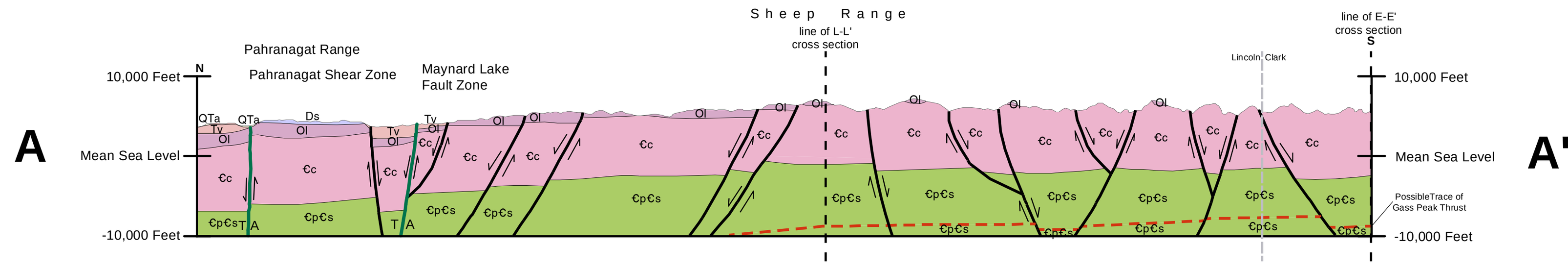
PLATE 4. CROSS SECTIONS SHOWING GEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

Explanation of Geologic Units
Shown on Cross Section

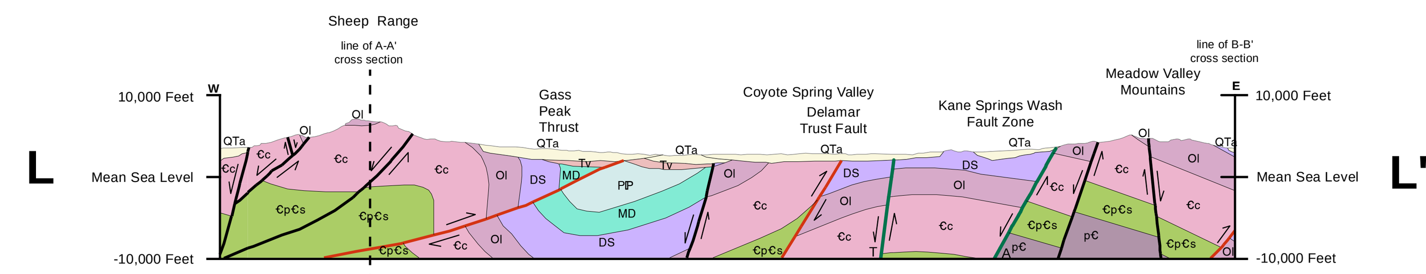
QTa	Quaternary and Tertiary basin-fill deposits
Tv	Tertiary volcanic ash-flows, flows and ash-fall tuffs
Ts4	Tertiary fluvial and lacustrine sediments
Tmb	Tertiary megabreccia
Ti	Tertiary intrusive rocks
Ks	Upper and Lower Cretaceous sedimentary rocks, undivided
Js	Jurassic sedimentary rocks, undivided
Ŧs	Triassic sedimentary rocks, undivided
Pp	Upper and Lower Permian Park City Group, undivided
PP	Permian and Pennsylvanian Riepe Spring Limestone and Ely Limestone, undivided
MD	Lower Mississippian to Upper Devonian Joana Limestone and Pilot Shale, undivided
D€	Devonian to Upper Cambrian sedimentary rocks, undivided
DS	Devonian and Silurian sedimentary rocks, undivided
Du	Devonian carbonate sedimentary rocks, undivided
Ds	Middle and Lower Devonian Simonson and Sevy Dolomites
Ol	Middle and Lower Ordovician, mostly Eureka Quartzite and the Pogonip Goup
€c	Cambrian carbonate sedimentary rocks, undivided
€p€s	Middle Cambrian to Late Proterozoic sedimentary rocks
p€	Late to Early Proterozoic metamorphosed and crystalline Precambrian basement rocks



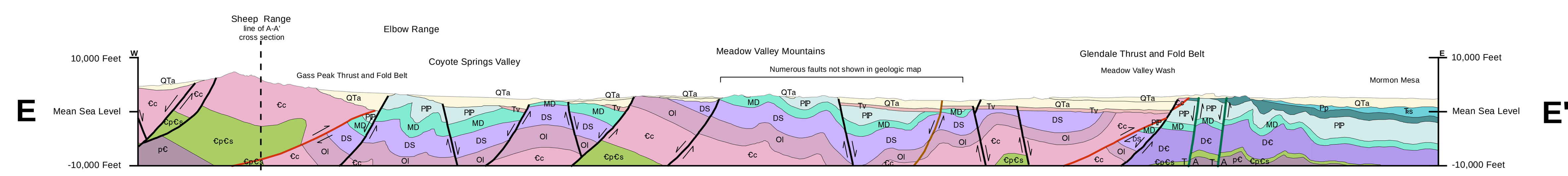
SECTION B - B'



SECTION A - A'



SECTION L - L'



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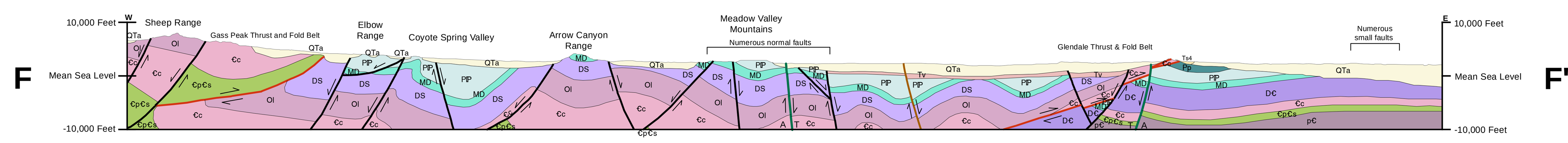
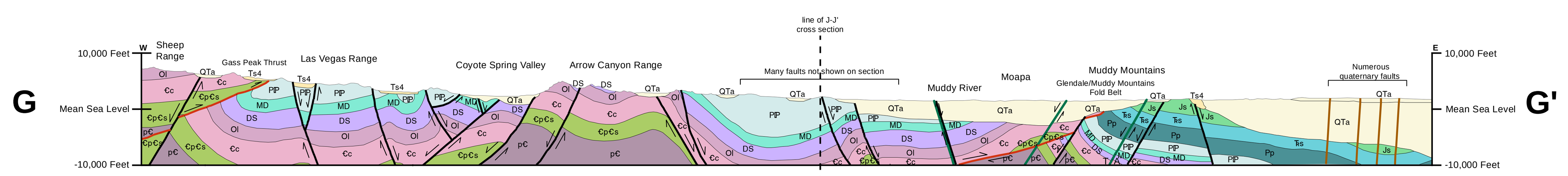
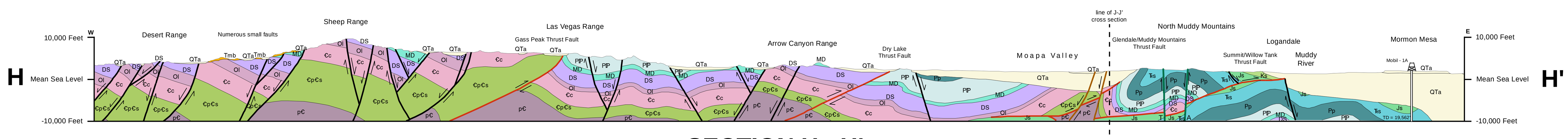


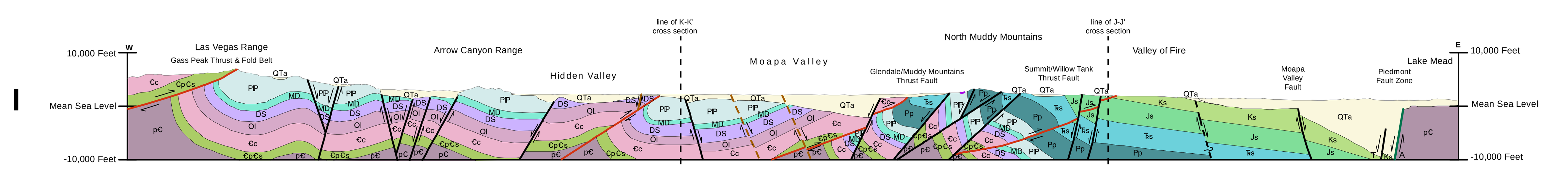
SECTION F - F'



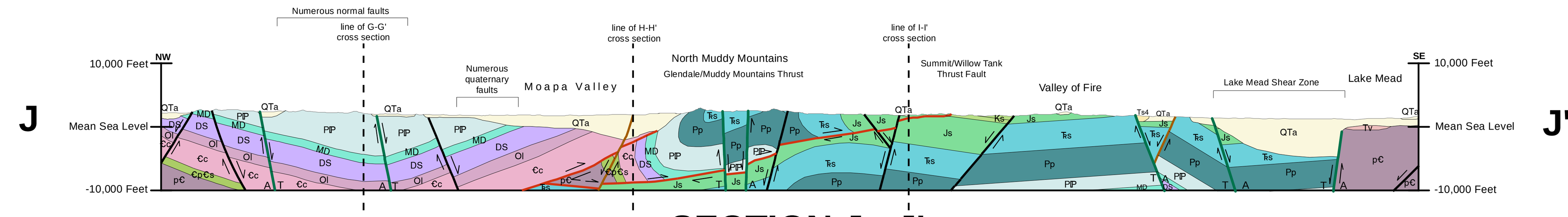
SECTION G - G'



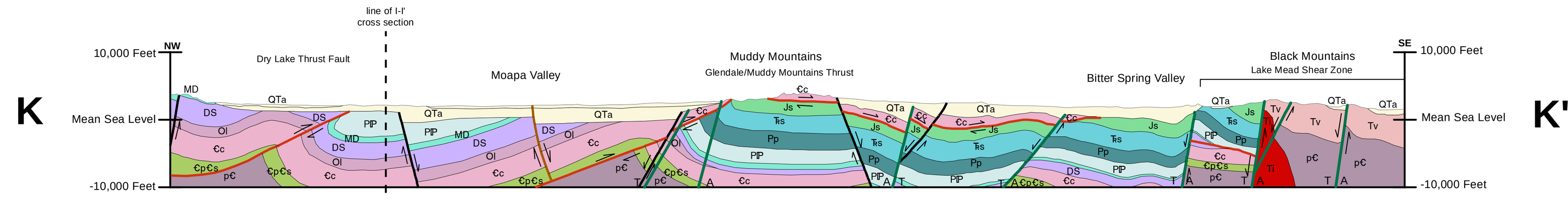
SECTION H - H'



SECTION I - I'



SECTION J - J'



SECTION K - K'

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

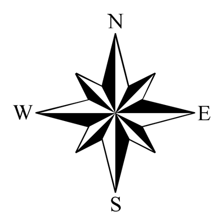
Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement. T= Towards, A = Away.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

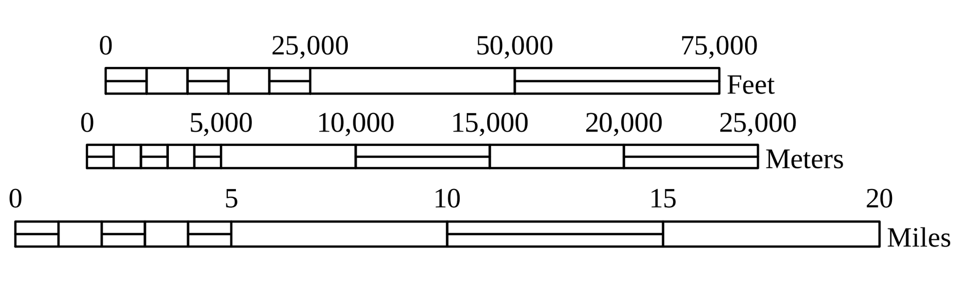
Well Name TD=1,234' — Oil Well Data Used in Cross Sections. TD = Total Depth (Feet)



SCALE 1:250,000

Projection: UTM Zone 11 NAD83

NO VERTICAL EXAGGERATION



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SOUTHERN NEVADA WATER AUTHORITY

PLATE 5. CROSS SECTIONS SHOWING GEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA

MAP ID 18434-3211 05/17/2011 BP

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SOUTHERN NEVADA WATER AUTHORITY

MAP ID 18286-3211 05/17/2011 JAB/BP

PLATE 1. GEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

PLATE 6. HYDROGEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

SNWA Exhibit 58

SOUTHERN NEVADA WATER AUTHORITY

MAP ID 18291-3211 06/02/2011 JAB/BP

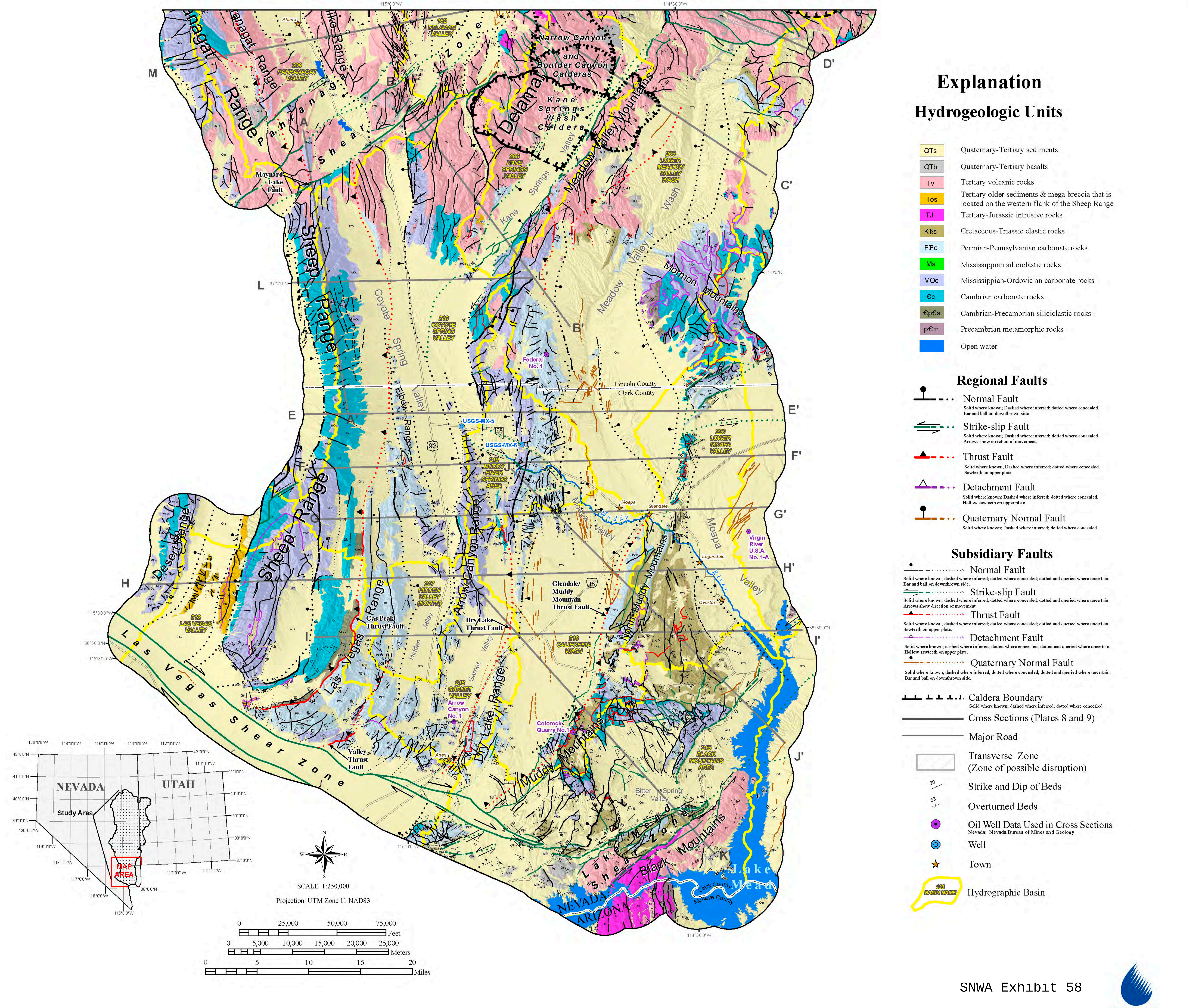

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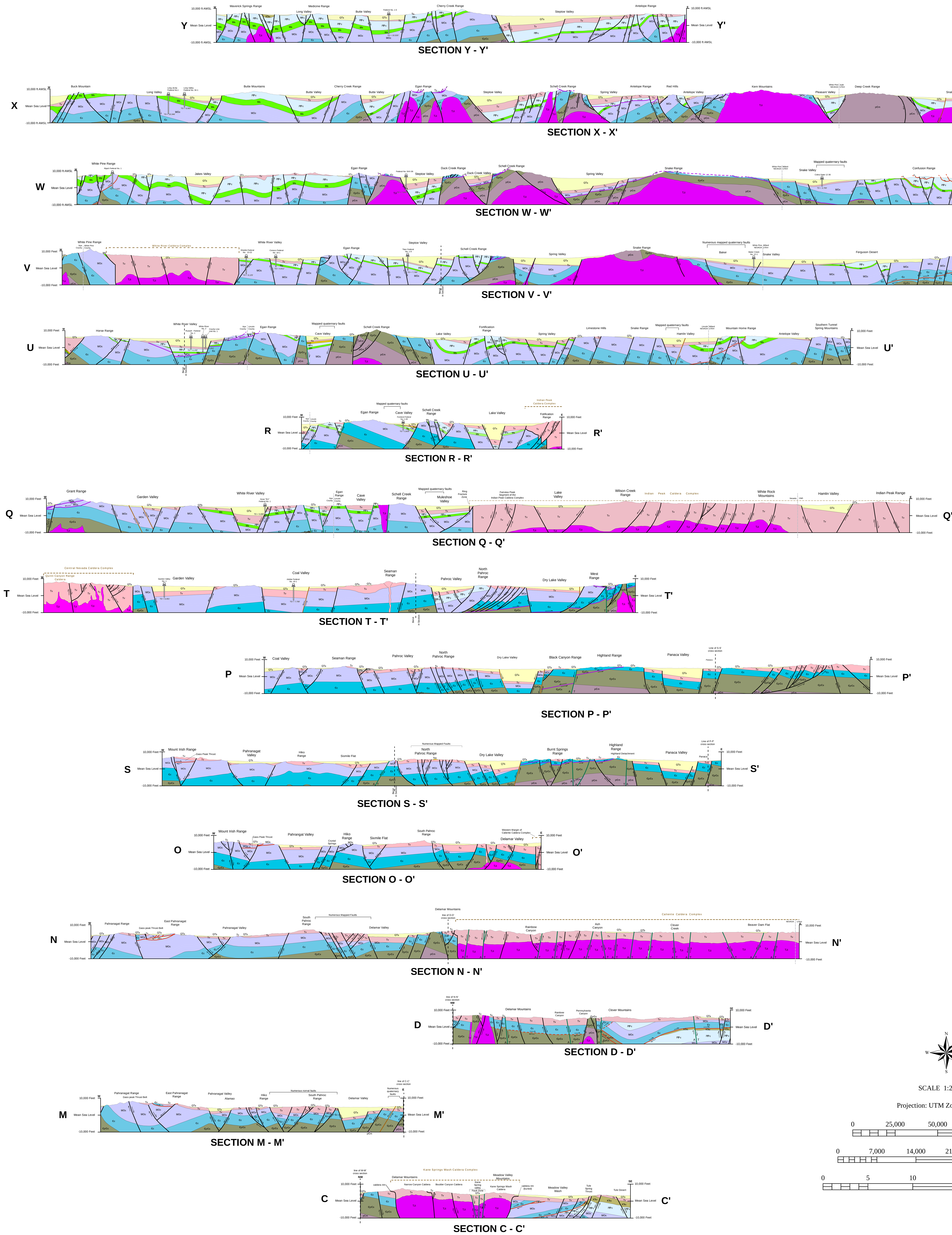
PLATE 7. HYDROGEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA, AND ADJACENT AREAS, ARIZONA



Explanation of Hydrogeologic Units

Shown on Cross Section

Unit	Description
QTs	Quaternary-Tertiary sediments
QTb	Quaternary-Tertiary basalts
Tv	Tertiary volcanic rocks
Tos	Tertiary older sediments
TJi	Tertiary-Jurassic intrusive rocks
KTs	Cretaceous-Triassic clastic rocks
PPc	Permian-Pennsylvanian carbonate rocks
Ms	Mississippian siliciclastic rocks
MOc	Mississippian-Ordovician carbonate rocks
Cc	Cambrian carbonate rocks
CpCs	Cambrian-Precambrian siliciclastic rocks
pCm	Precambrian metamorphic rocks

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement. T= Towards, A = Away.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed. Arrows show direction of movement.

Well Name
TD=1,234'

Oil Well Data Used in Cross Sections
TD = Total Depth (Feet)

SCALE 1:250,000

Projection: UTM Zone 11 NAD83

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SOUTHERN NEVADA WATER AUTHORITY

PLATE 8. CROSS SECTIONS SHOWING HYDROGEOLOGY OF WHITE PINE AND NORTHERN LINCOLN COUNTIES, NEVADA, AND ADJACENT AREAS, NEVADA AND UTAH

MAP ID 18435-3211 05/17/2011 BP

Explanation of Hydrogeologic Units
Shown on Cross Section

Symbol	Unit
QTs	Quaternary-Tertiary sediments
Tv	Tertiary volcanic rocks
TJi	Tertiary-Jurassic intrusive rocks
KTRs	Cretaceous-Triassic clastic rocks
PIPc	Permian-Pennsylvanian carbonate rocks
MOc	Mississippian-Ordovician carbonate rocks
Ꞓc	Cambrian carbonate rocks
ꞒpꞒs	Cambrian-Precambrian siliciclastic rocks
pꞒm	Precambrian metamorphic rocks

Geologic Structure

Normal Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

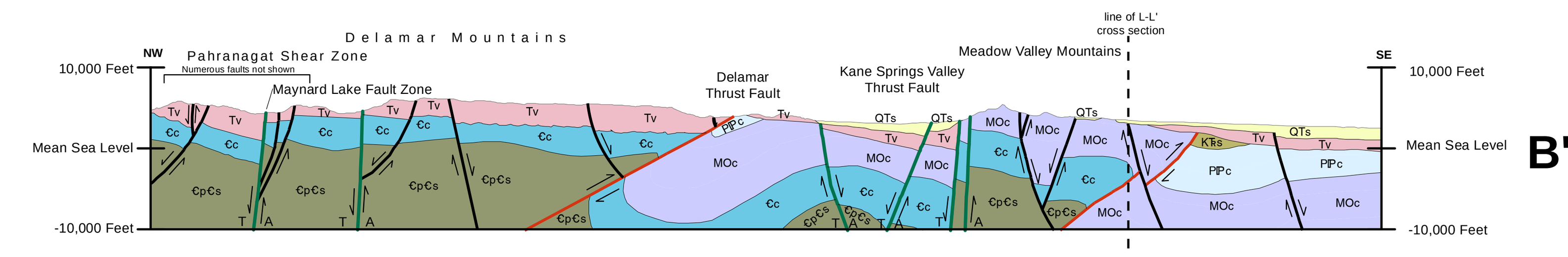
Strike-slip Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement. T= Towards, A = Away.

Thrust Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

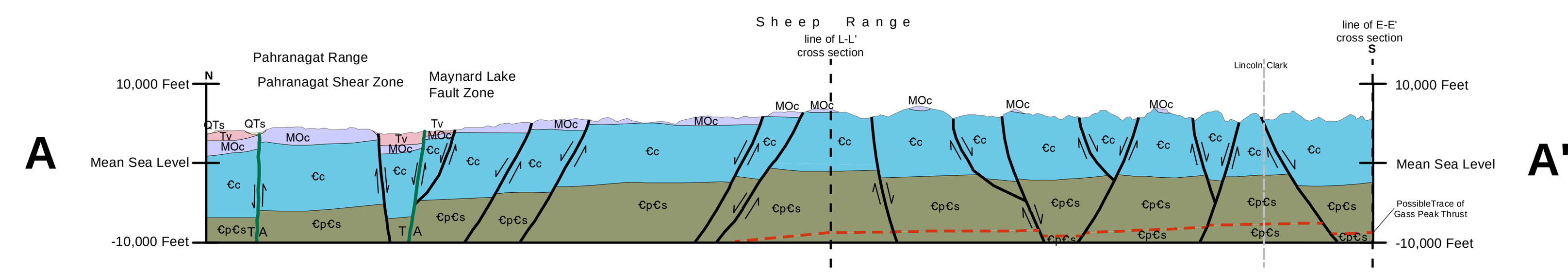
Detachment Fault
Solid where known; Dashed where inferred; dotted where concealed.

Quaternary Fault
Solid where known; Dashed where inferred; dotted where concealed.
Arrows show direction of movement.

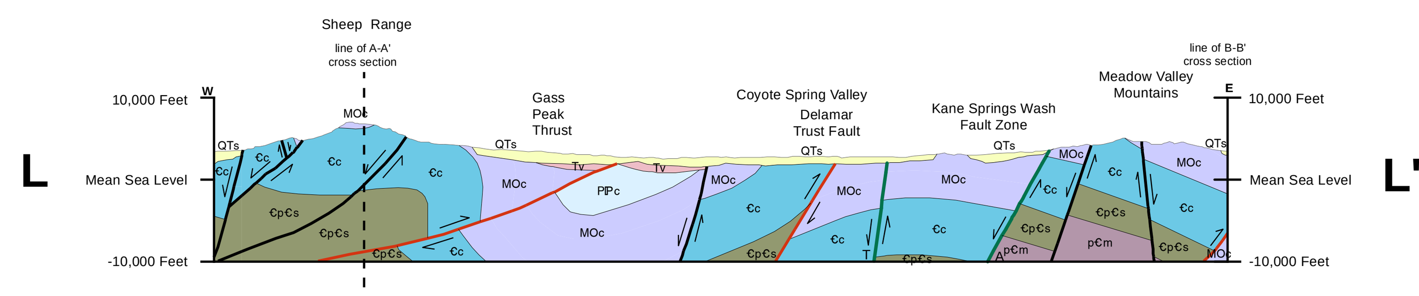
Well Name
TD=1,234'
Oil Well Data Used in Cross Sections
TD = Total Depth (Feet)



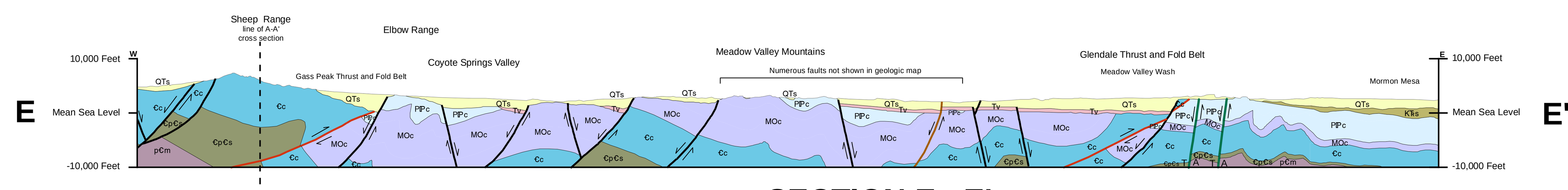
SECTION B - B'



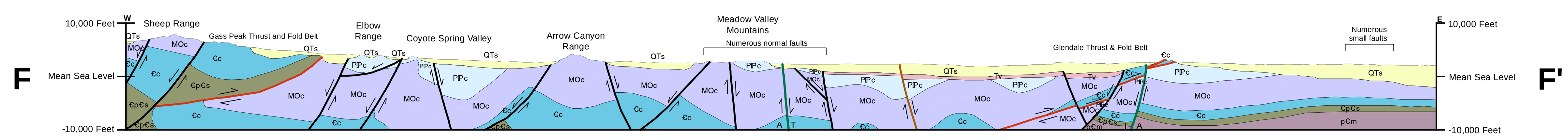
SECTION A - A'



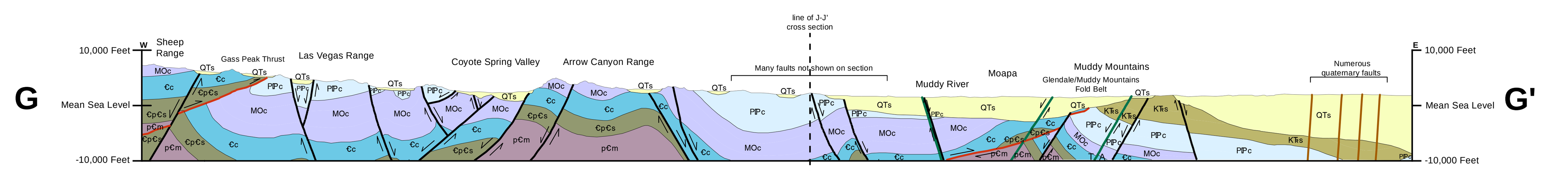
SECTION L - L'



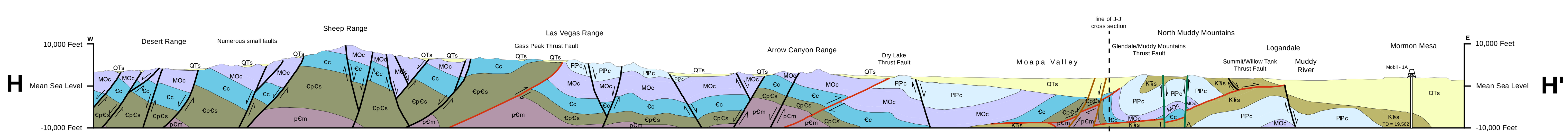
SECTION E - E'



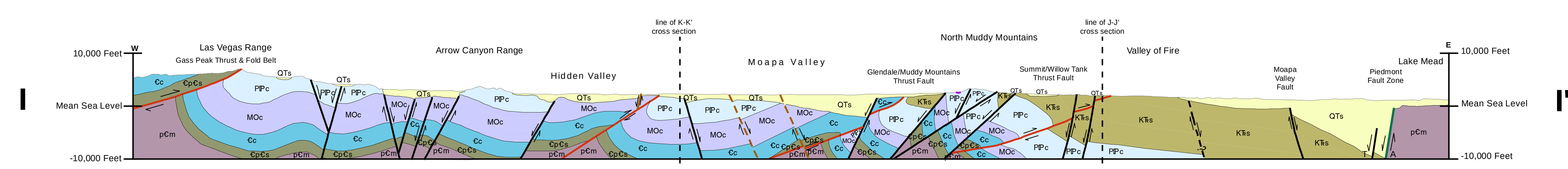
SECTION F - F'



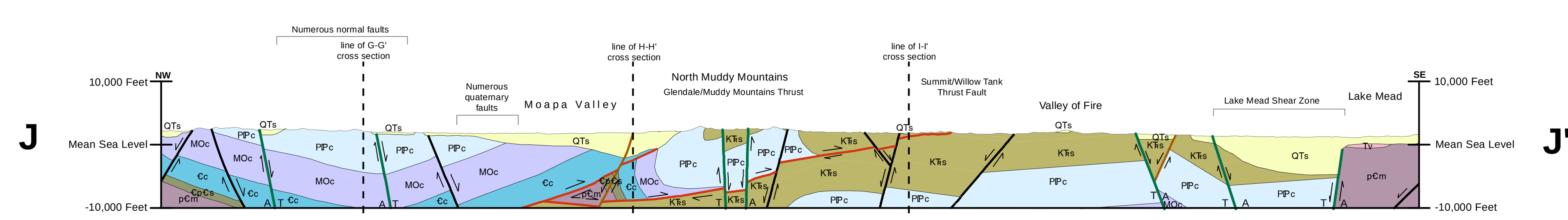
SECTION G - G'



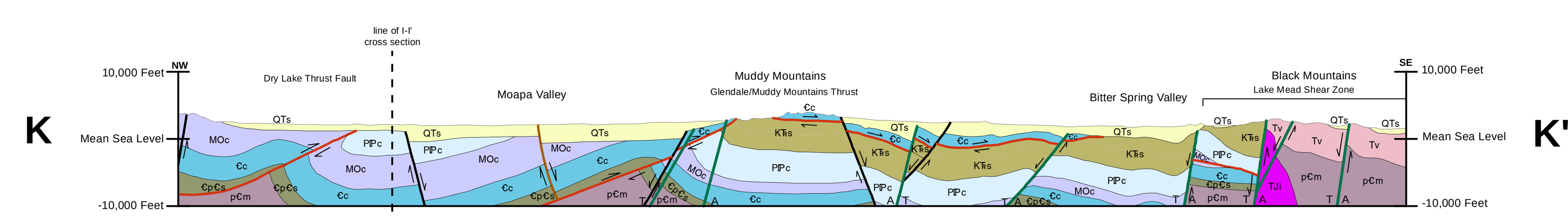
SECTION H - H'



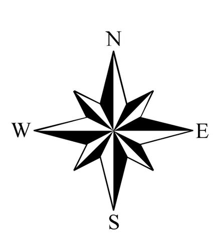
SECTION I - I'



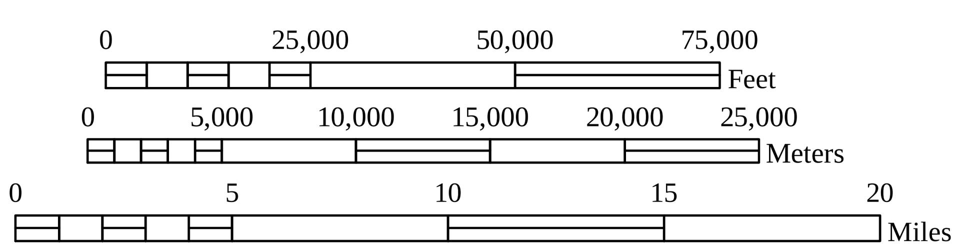
SECTION J - J'



SECTION K - K'



SCALE 1:250,000
Projection: UTM Zone 11 NAD83
NO VERTICAL EXAGGERATION



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SOUTHERN NEVADA WATER AUTHORITY

PLATE 9. CROSS SECTIONS SHOWING HYDROGEOLOGY OF SOUTHERN LINCOLN AND NORTHERN CLARK COUNTIES, NEVADA

MAP ID 18436-3211 05/17/2011 BP

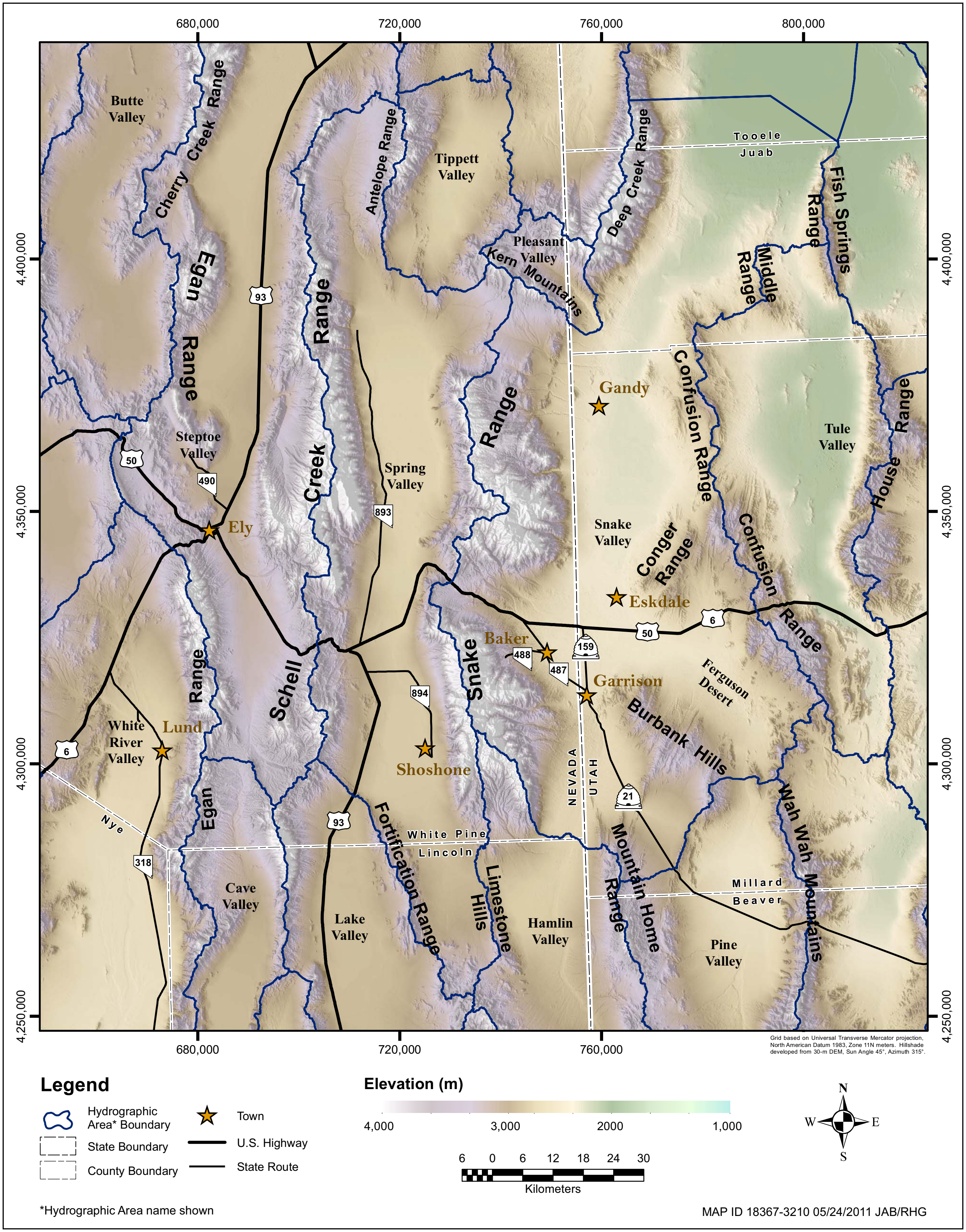

Figure 5-2
Shaded Relief Map of Spring and Snake Valleys and Vicinity, Nevada and Utah

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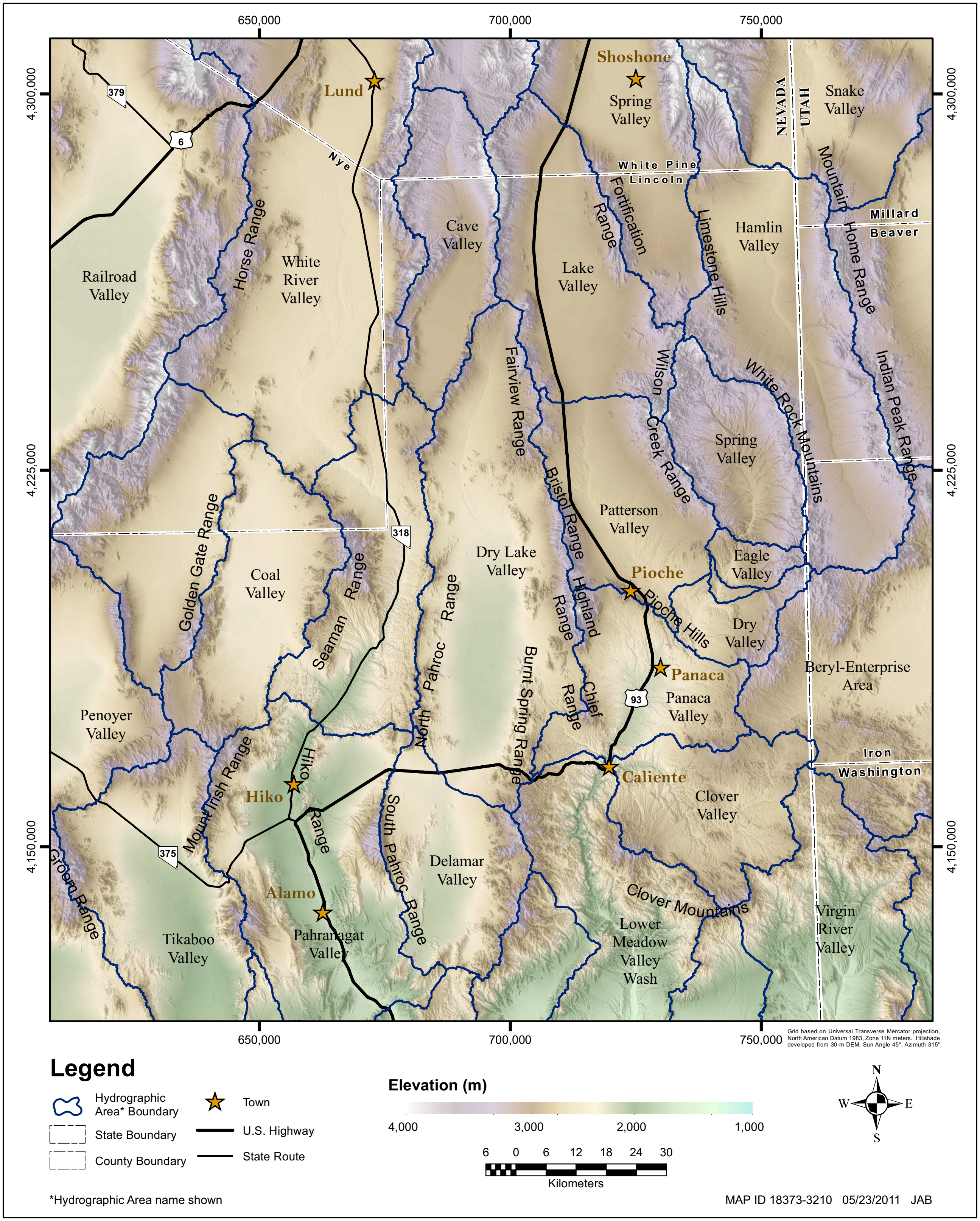
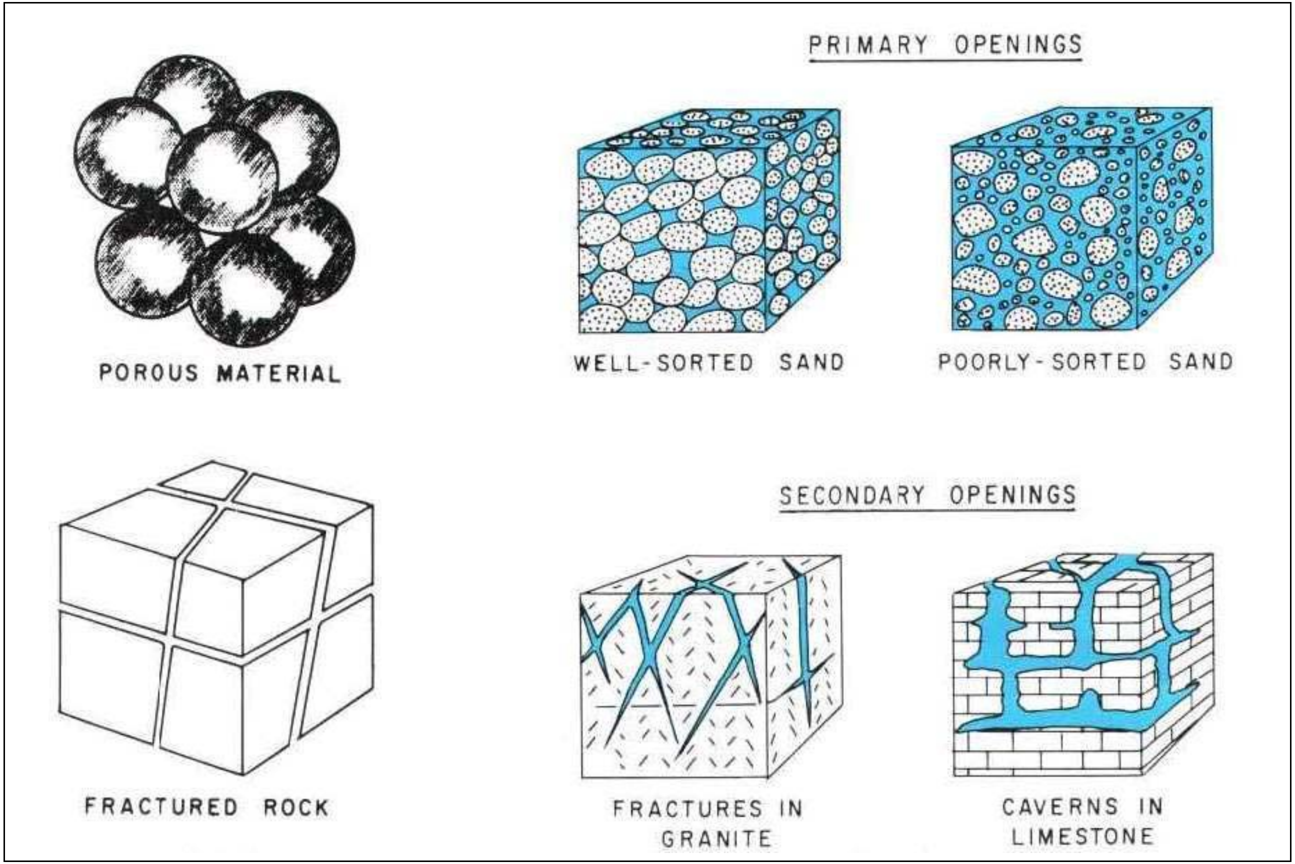


Source: Mankinen et al. (2008)

Figure 5-10
Shaded Relief Map of Cave, Dry Lake, and Delamar Valleys and Vicinity, Nevada



Source: Modified from Heath (1983)

Figure 2-3
Schematic of Primary and Secondary Porosities/Permeabilities of Rock Matrices

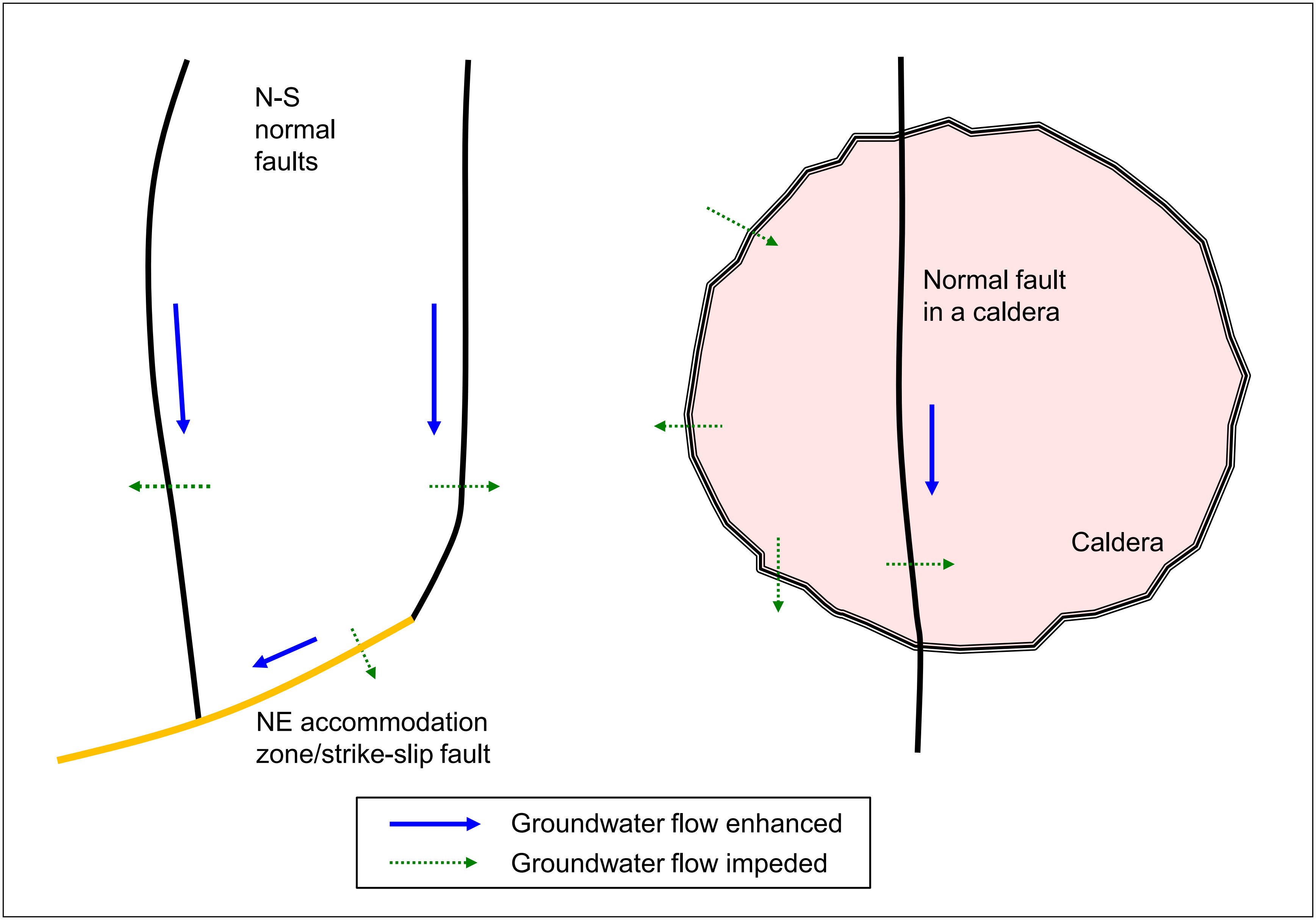
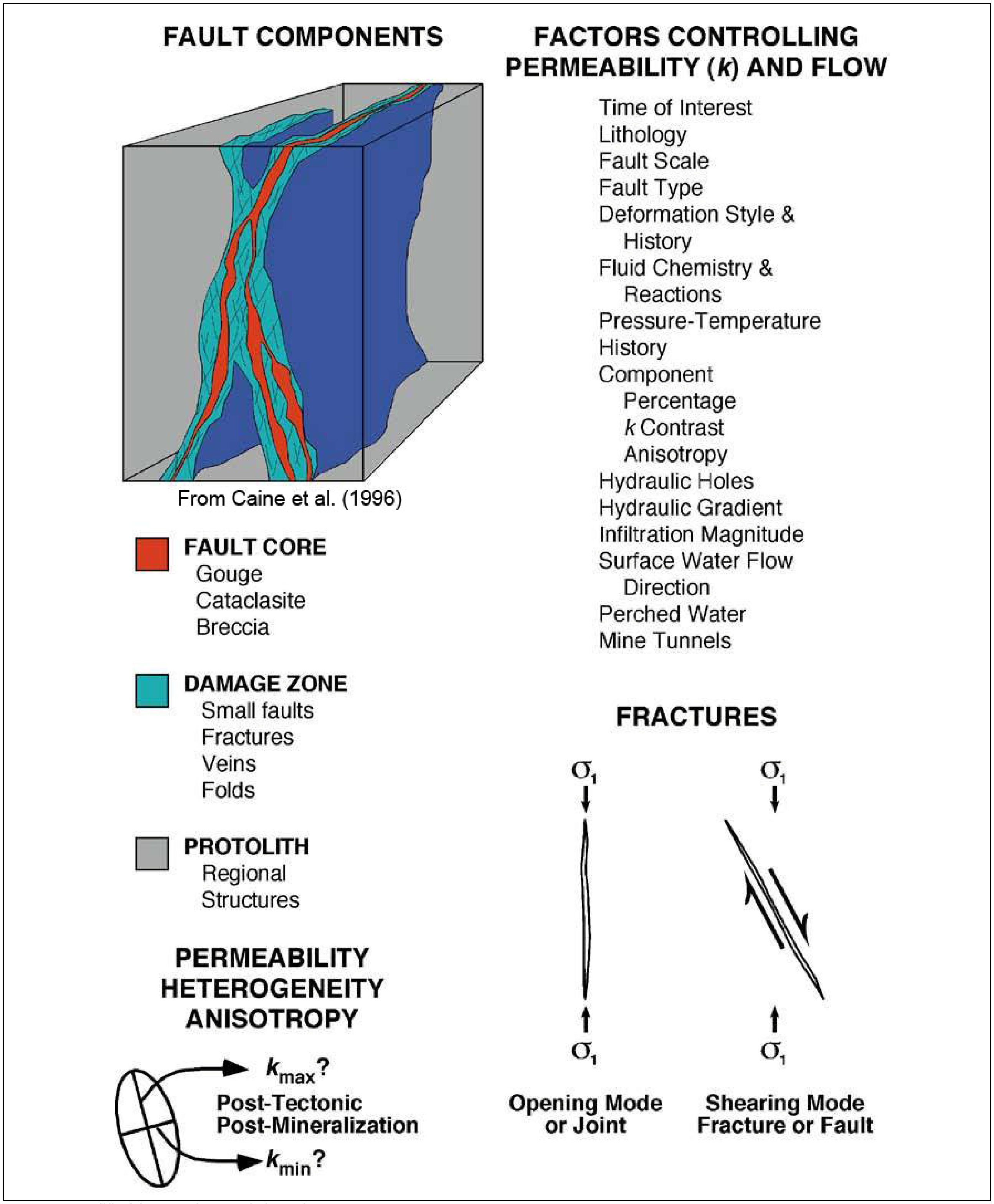


Figure 2-5
Map Showing Enhancement/Impedance of Groundwater Flow along or across Faults and Calderas



Source: Modified from Caine et al. (2010)

Figure 2-4
Conceptualization of Fault Components and Factors Controlling Permeability and Groundwater Flow

Fault zone architecture and permeability structure

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James P. Evans Department of Geology, Utah State University, Logan, Utah 84322-4505
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ABSTRACT

Fault zone architecture and related permeability structures form primary controls on fluid flow in upper-crustal, brittle fault zones. We develop qualitative and quantitative schemes for evaluating fault-related permeability structures by using results of field investigations, laboratory permeability measurements, and numerical models of flow within and near fault zones. The qualitative scheme compares the percentage of the total fault zone width composed of fault core materials (e.g., anastomosing slip surfaces, clay-rich gouge, cataclasite, and fault breccias) to the percentage of subsidiary damage zone structures (e.g., kinematically related fracture sets, small faults, and veins). A more quantitative scheme is developed to define a set of indices that characterize fault zone architecture and spatial variability. The fault core and damage zone are distinct structural and hydrogeologic units that reflect the material properties and deformation conditions within a fault zone. Whether a fault zone will act as a conduit, barrier, or combined conduit-barrier system is controlled by the relative percentage of fault core and damage zone structures and the inherent variability in grain scale and fracture permeability. This paper outlines a framework for understanding, comparing, and correlating the fluid flow properties of fault zones in various geologic settings.

INTRODUCTION

Brittle fault zones are lithologically heterogeneous and structurally anisotropic discontinuities in the upper crust. They may act as conduits, barriers, or combined conduit-barrier systems that enhance or impede fluid flow (Randolph and Johnson, 1989; Smith et al., 1990; Scholz, 1990; Caine et al., 1993; Forster et al., 1994; Antonellini and Aydin, 1994; Newman and Mitra, 1994; Goddard and Evans, 1995). Fault zones are composed of distinct components: a fault core where most of the displacement is accommodated and an associated damage zone that is mechanically related to the growth of the fault zone (Sibson, 1977; Chester and Logan, 1986; Davison and Wang, 1988; Forster and Evans, 1991; Byerlee, 1993; Scholz and Anders, 1994). The amount and distribution of each component control fluid flow within and near the fault zone.

Insufficient data, particularly field-based data, are available to adequately characterize and compare architecture, permeability structure, fluid flow, and mechanical properties of fault zones found in different geologic environments. Current demands to prove the long-term integrity of waste-disposal facilities, produce hydrocarbons from reservoirs compartmentalized by fault zones, extract mineral deposits, and estimate earthquake risk require incorporating detailed, field-based representations of the physical properties of fault zones in predictive fluid flow simulators. Development of valid flow models is hindered by our inability to measure in situ fault zone properties in a way that adequately characterizes the spatial and temporal variations in permeability, porosity, and storativity.

In this paper, we compile data, terminology, and conceptual models in order to consolidate our knowledge of fault-related permeability structures. We outline a fault zone model and a set of indices that serve as a guide in evaluating the physical properties of fault zones. This model can be used as a framework for determining spatial variability in fault zone architecture from field data and for incorporating physically based geologic information in mathematical models of fluid flow in faulted rocks. We first define the major components of a fault zone and then set forth both qualitative and quantitative schemes for fault-related permeability structures. The schemes are based on a synopsis of our research and the work of other authors (Sibson, 1981; Oliver, 1986; Chester and Logan, 1986; Parry and Bruhn, 1986; Scholz, 1987; Scholz and Anders, 1994; Parry et al., 1988; Bruhn et al., 1990; Smith et al., 1990; Forster and Evans, 1991; Moore and Vrolijk, 1992; Caine et al., 1993; Newman and Mitra, 1994; Goddard and Evans, 1995).

FAULT ZONE DEFINITION

The primary components of upper-crustal fault zones are fault core, damage zone, and protolith (shown in the conceptual model of Fig. 1). No scalar relationship is implied between the components, nor must all of the components be present in any given fault zone. Note that the fluid flow properties of a fault zone may change, thus the diagram represents only a single point in time. For example, the core may act as a conduit during deformation and as a barrier when open pore space is filled by mineral precipitation following deformation. Thus, it is important to specify the stage of fault evolution when forming a conceptual model for a particular fault zone.

We define a fault core as the structural, lithologic, and morphologic portion of a fault zone where most of the displacement is

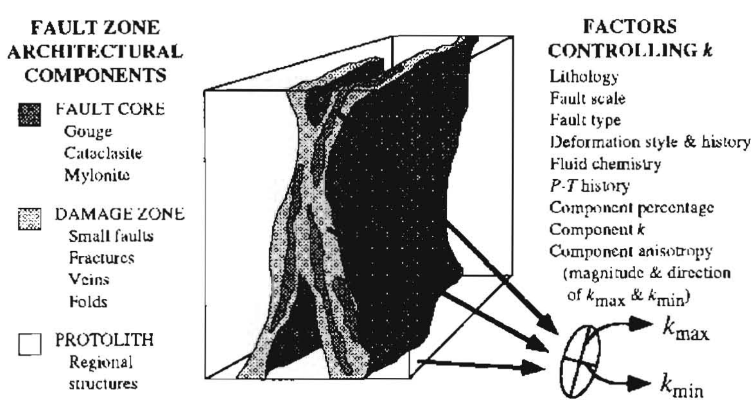

Figure 1. Conceptual model of fault zone with protolith removed (after Chester and Logan, 1986; Smith et al., 1990). Ellipse represents relative magnitude and orientation of the bulk two-dimensional permeability (*k*) tensor that might be associated with each distinct architectural component of fault zone.

Data Repository item 9659 contains additional material related to this article.

Fault zone architecture and permeability structure

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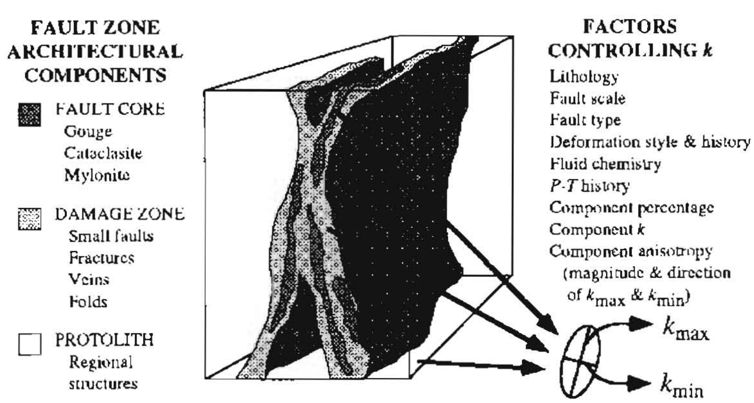

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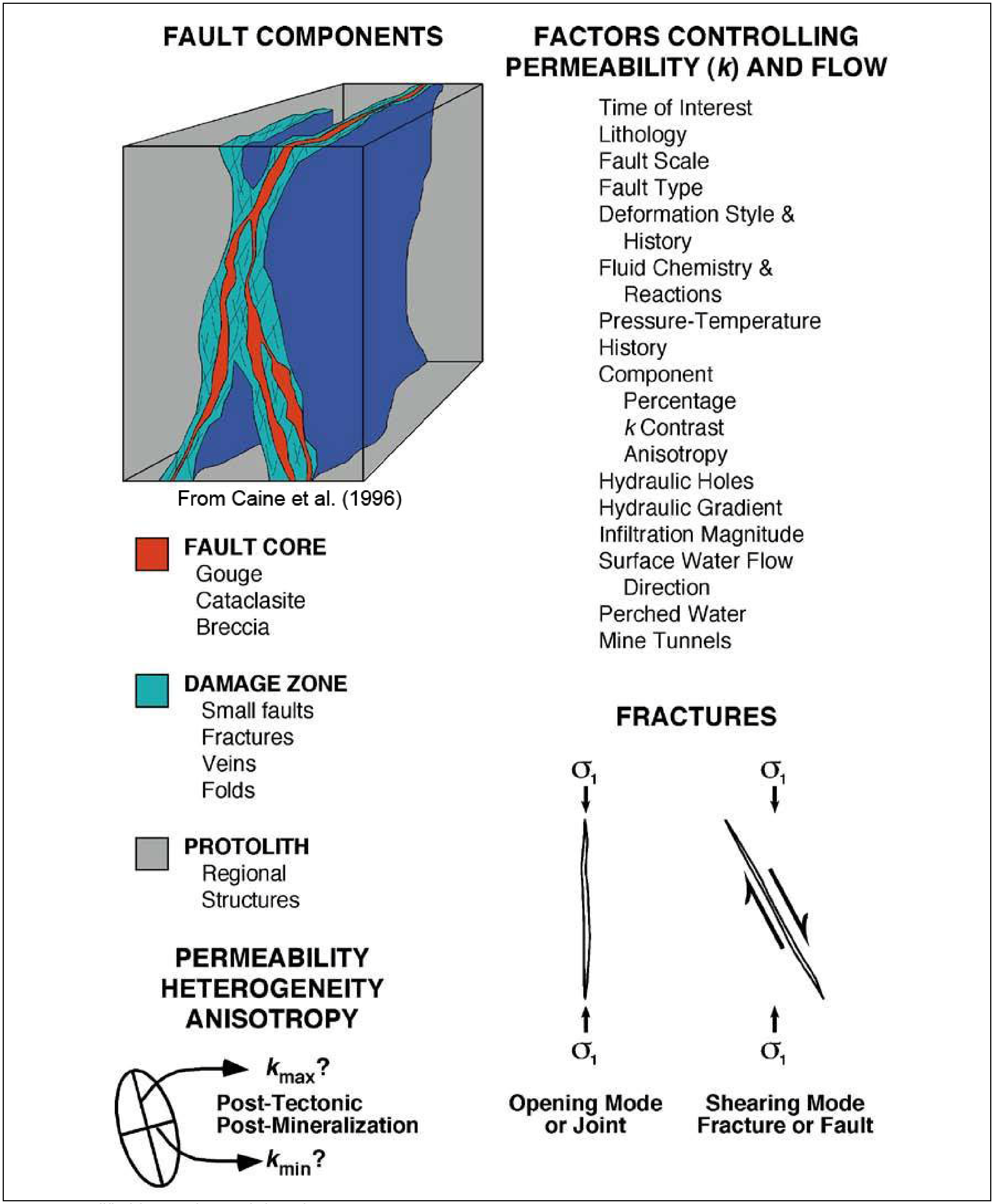

Source: Modified from Caine et al. (2010)

Figure 2-4
Conceptualization of Fault Components and Factors Controlling Permeability and Groundwater Flow

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component of the fault zone from which samples and related data are collected.

Field observations of unfractured fault core materials suggest that they are dominated by grain-scale permeability. Laboratory-determined permeabilities for natural fault core materials show a range of variation of approximately 10 orders of magnitude (10^{-12} to 10^{-22} m^2 from Smith et al., 1990). These data suggest that the permeability of fault core materials depends, in part, on lithology and the degree to which that lithology has been chemically altered. Rocks with the lowest phyllosilicate content tend to have the highest permeability. If there is a direct correlation between protolith rock type and the types of fault core materials that develop in a given deformation environment, then a predictive link may be made with the resulting conduit-barrier systematics.

Although fault zone core materials often have low matrix permeability, they may not always act as a barrier to flow, particularly during deformation. For example, work on the Dixie Valley fault zone shows that the fault core acted as a short-lived, syndeformational, fluid flow conduit that then rapidly sealed to form a barrier to flow. This history is also indicated from work on fault 6, Traill Ø, East Greenland. In contrast, damage zones tend to be conduits compared with both the fault core and the often lower or "background" permeability of the protolith.

In spite of the dearth of laboratory-determined grain-scale permeability values from samples of damage zone materials, our field observations suggest that damage zone permeability is fracture dominated. The juxtaposition of highly fractured damage zone materials with undeformed protolith and generally unfractured fault core materials forms major permeability contrasts within a fault zone. Preliminary estimates of damage zone fracture permeability, using the fracture-permeability estimation methods of Oda et al. (1987) and Bruhn (1993), in both the Dixie Valley fault zone and fault 6, are two to three orders of magnitude greater than the permeability of fractured protolith and four to six orders of magnitude greater than the fault core grain-scale permeabilities. The magnitude and spatial variability of this permeability contrast may be the primary control on fault zone barrier-conduit systematics.

Additional controls on fault zone architecture and permeability structure may include deformation conditions and the chemistry of fault zone fluids. Understanding the combined impact of mechanical and chemical changes in each of the three fault zone components on overall architecture and permeability structure is crucial to a better understanding of heterogeneity and anisotropy in fault zones. Field-based fault zone architectural data can then be evaluated in the context of permeability structure and formative deformation processes by using the quantitative scheme and architectural indices.

CONCLUSIONS

Fluid flow in upper-crustal, brittle fault zones depends on fault zone architecture and permeability structure. We represent these aspects of fault zone structure and hydrogeology in the qualitative and quantitative schemes presented in this paper. The schemes are based on a three-component fault zone model that includes a fault core, damage zone, and protolith. This conceptual model is used to delineate the distinct structural and hydrogeologic regimes of a fault zone. A conceptual scheme with four end members is used to identify the range of possible and observed configurations of the three fault zone components. A second, more quantitative scheme, represents variations in fault zone structure by using architectural indices. Adopting these schemes provides a consistent framework for evaluating how the permeability structure of fault zones controls fluid flow in diverse structural regimes.

There is a clear need to continue field-based characterization and sample collection to determine the factors that control fluid flow in fault zones. This work should be done in each fault zone component, on a variety of fault zone types developed within different lithologies over a broad range of scales. Once refined quantitative data are added to the scheme, new axes may be added. These might include time or lithology axes that would make the schemes more comprehensive and possibly provide a predictive tool for better understanding fault zone architecture and permeability structure. The role of fluids in faulting processes, as well as the growing concerns of fault-related utilization of ground-water, hydrocarbon, mineral, and geothermal resources, makes understanding and characterizing fault zone architecture and permeability structure critical at various times throughout the evolution of a fault zone.

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component of the fault zone from which samples and related data are collected.

Field observations of unfractured fault core materials suggest that they are dominated by grain-scale permeability. Laboratory-determined permeabilities for natural fault core materials show a range of variation of approximately 10 orders of magnitude (10^{-12} to 10^{-22} m^2 from Smith et al., 1990). These data suggest that the permeability of fault core materials depends, in part, on lithology and the degree to which that lithology has been chemically altered. Rocks with the lowest phyllosilicate content tend to have the highest permeability. If there is a direct correlation between protolith rock type and the types of fault core materials that develop in a given deformation environment, then a predictive link may be made with the resulting conduit-barrier systematics.

Although fault zone core materials often have low matrix permeability, they may not always act as a barrier to flow, particularly during deformation. For example, work on the Dixie Valley fault zone shows that the fault core acted as a short-lived, syndeformational, fluid flow conduit that then rapidly sealed to form a barrier to flow. This history is also indicated from work on fault 6, Traill Ø, East Greenland. In contrast, damage zones tend to be conduits compared with both the fault core and the often lower or "background" permeability of the protolith.

In spite of the dearth of laboratory-determined grain-scale permeability values from samples of damage zone materials, our field observations suggest that damage zone permeability is fracture dominated. The juxtaposition of highly fractured damage zone materials with undeformed protolith and generally unfractured fault core materials forms major permeability contrasts within a fault zone. Preliminary estimates of damage zone fracture permeability, using the fracture-permeability estimation methods of Oda et al. (1987) and Bruhn (1993), in both the Dixie Valley fault zone and fault 6, are two to three orders of magnitude greater than the permeability of fractured protolith and four to six orders of magnitude greater than the fault core grain-scale permeabilities. The magnitude and spatial variability of this permeability contrast may be the primary control on fault zone barrier-conduit systematics.

Additional controls on fault zone architecture and permeability structure may include deformation conditions and the chemistry of fault zone fluids. Understanding the combined impact of mechanical and chemical changes in each of the three fault zone components on overall architecture and permeability structure is crucial to a better understanding of heterogeneity and anisotropy in fault zones. Field-based fault zone architectural data can then be evaluated in the context of permeability structure and formative deformation processes by using the quantitative scheme and architectural indices.

CONCLUSIONS

Fluid flow in upper-crustal, brittle fault zones depends on fault zone architecture and permeability structure. We represent these aspects of fault zone structure and hydrogeology in the qualitative and quantitative schemes presented in this paper. The schemes are based on a three-component fault zone model that includes a fault core, damage zone, and protolith. This conceptual model is used to delineate the distinct structural and hydrogeologic regimes of a fault zone. A conceptual scheme with four end members is used to identify the range of possible and observed configurations of the three fault zone components. A second, more quantitative scheme, represents variations in fault zone structure by using architectural indices. Adopting these schemes provides a consistent framework for evaluating how the permeability structure of fault zones controls fluid flow in diverse structural regimes.

There is a clear need to continue field-based characterization and sample collection to determine the factors that control fluid flow in fault zones. This work should be done in each fault zone component, on a variety of fault zone types developed within different lithologies over a broad range of scales. Once refined quantitative data are added to the scheme, new axes may be added. These might include time or lithology axes that would make the schemes more comprehensive and possibly provide a predictive tool for better understanding fault zone architecture and permeability structure. The role of fluids in faulting processes, as well as the growing concerns of fault-related utilization of ground-water, hydrocarbon, mineral, and geothermal resources, makes understanding and characterizing fault zone architecture and permeability structure critical at various times throughout the evolution of a fault zone.

ACKNOWLEDGMENTS

We thank Arild Andresen of the University of Oslo for support of field work in East Greenland, Exxon Production Research Company for support of field and laboratory work in east Greenland. U.S. Geological Survey National Earthquake Hazards Reduction Program grant 1434-93-G-2280 (to Forster, R. L. Bruhn, and J. Fredrich) for support of work on the Dixie Valley fault zone, and National Science Foundation grant 92-05774 and U.S. Geological Survey National Earthquake Hazards Reduction Program grant 1434-94-G-2468 (to Evans).

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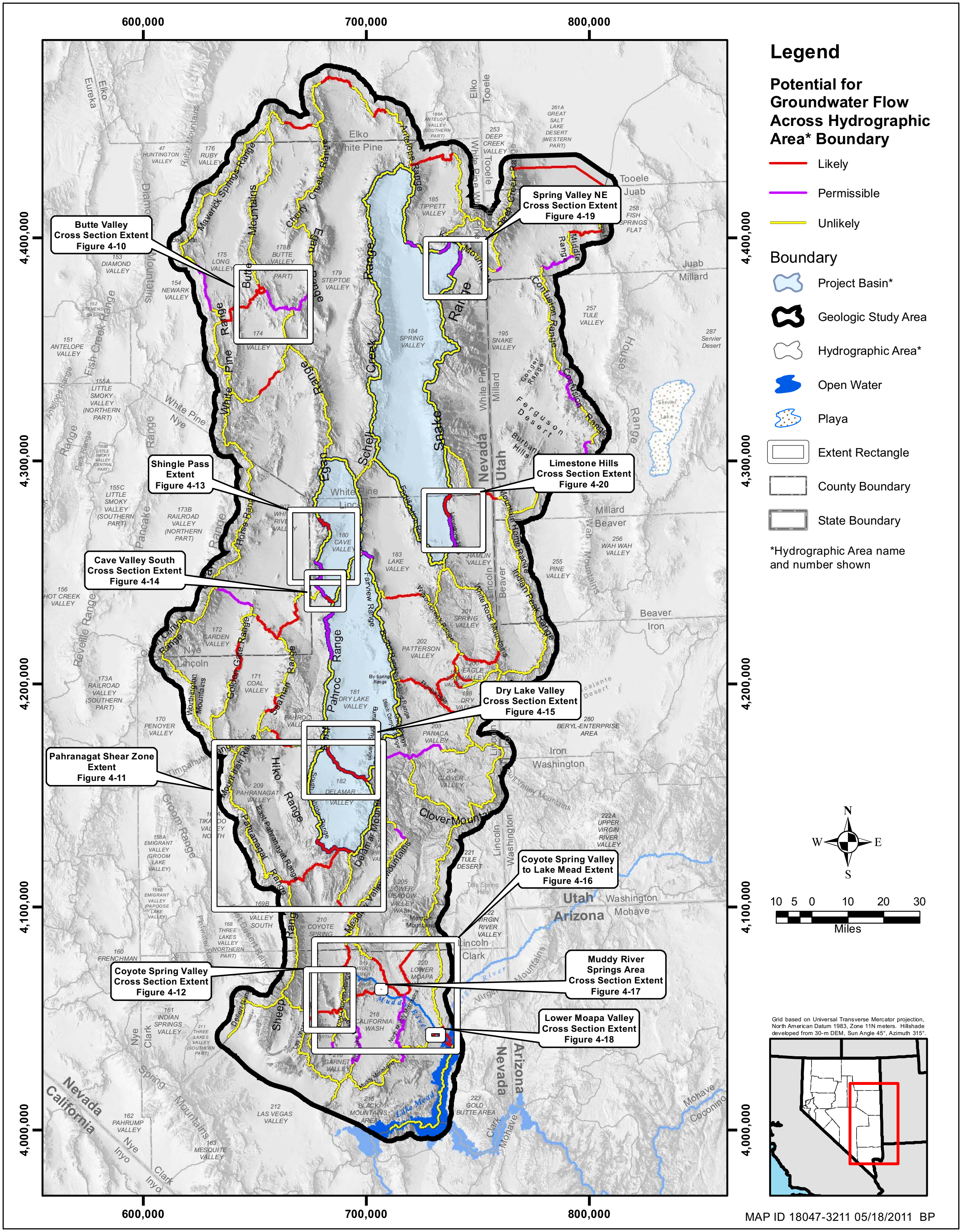
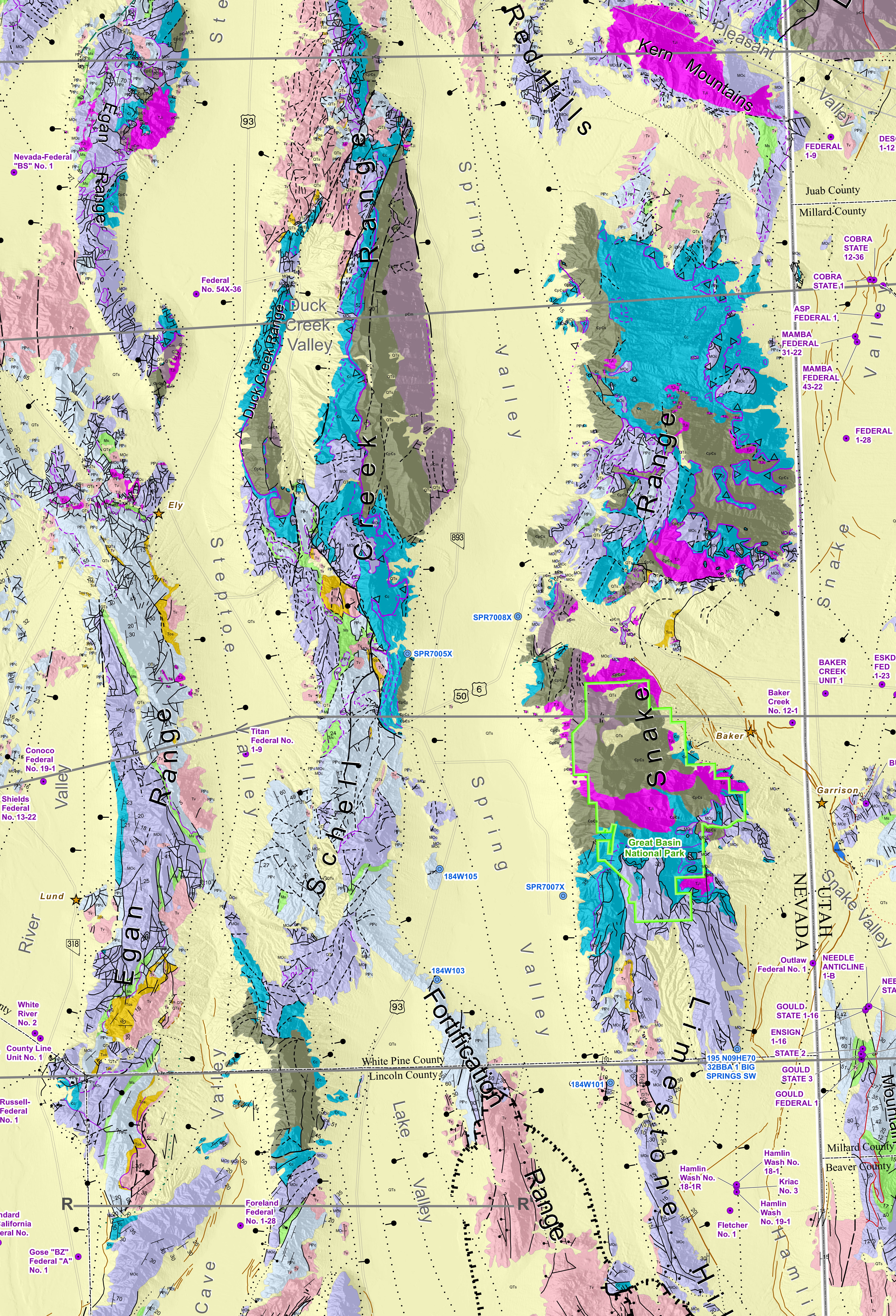


Figure 4-9

Potential for Interbasin Groundwater Flow within the Geologic Study Area

SNWA Exhibit 58



Egan Range
Nevada-Federal "BS" No. 1
Federal No. 54X-36
Duck Creek Valley
Duck Creek Range
Duck Creek Range
Spring Valley
Red Hills
Kern Mountains
Pleasant Valley
FEDERAL 1-9
Juab County
Millard County
COBRA STATE 12-36
COBRA STATE 1
ASP FEDERAL 1
MAMBA FEDERAL 31-22
MAMBA FEDERAL 43-22
FEDERAL 1-28
Snake Range
Snake Valley
Ely
Steptoe Valley
SPR7008X
SPR7005X
893
50
6
93
BAKER CREEK UNIT 1
Baker Creek No. 12-1
Baker
Garrison
Titan Federal No. 1-9
Conoco Federal No. 19-1
Shields Federal No. 13-22
Schell Creek Range
Great Basin National Park
184W105
SPR7007X
Lund
318
River
NEVADA
UTAH
Snake Valley
Outlaw Federal No. 1
NEEDLE ANTICLINE 1-B
184W103
Fortification Range
GOULD STATE 1-16
ENSIGN 1-16
STATE 2
GOULD STATE 3
GOULD FEDERAL 1
White River No. 2
County Line Unit No. 1
White Pine County
Lincoln County
195 N09HE70 32BBA 1 BIG SPRINGS SW
184W101
Russell-Federal No. 1
Cave Valley
Lake Valley
Limestone Hills
Hamlin Wash No. 18-1R
Hamlin Wash No. 18-1
Kriac No. 3
Hamlin Wash No. 19-1
Fletcher No. 1
Millard County
Beaver County
Foreland Federal No. 1-28
Gose "BZ" Federal "A" No. 1
R
R

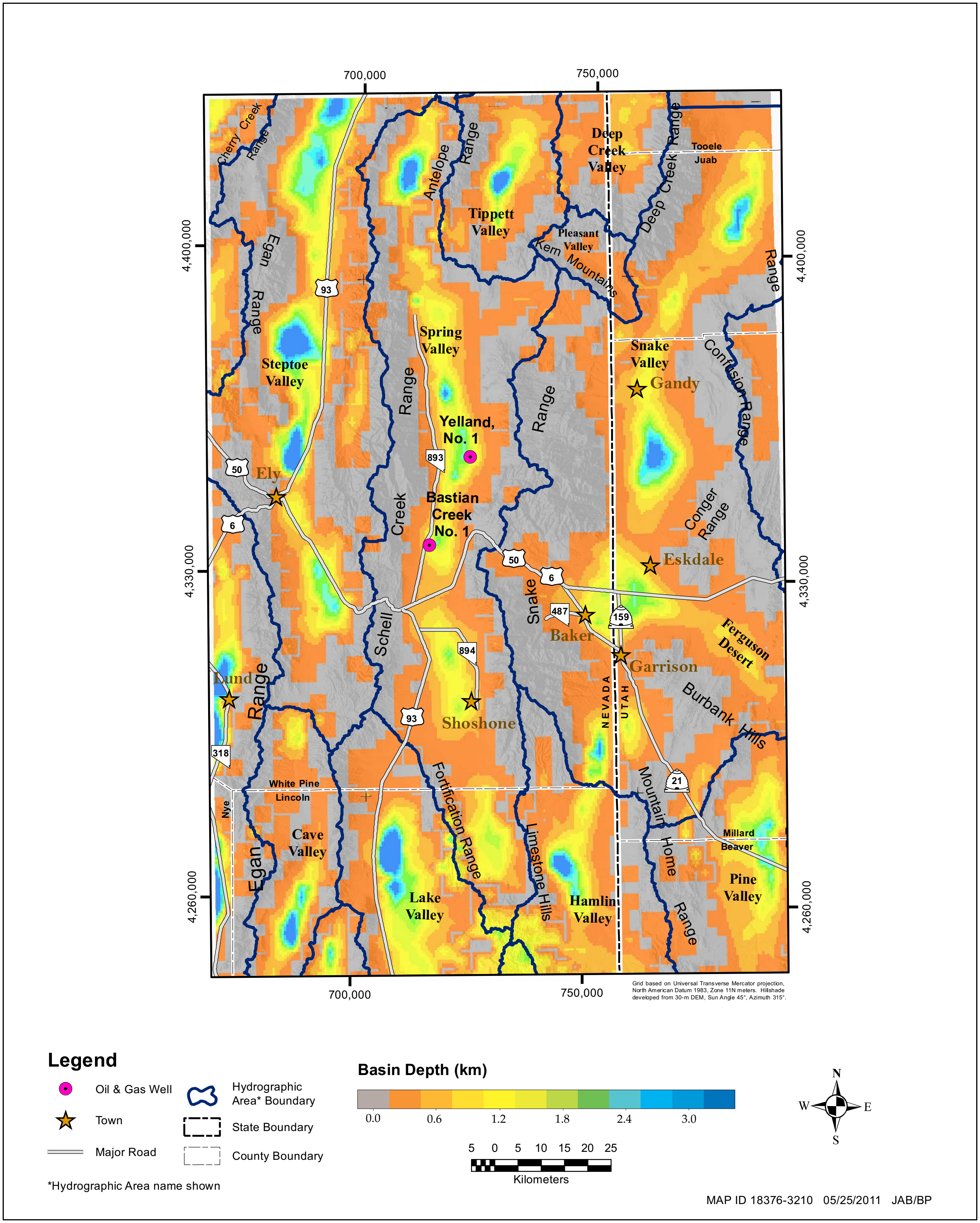


Figure 5-5
Depth to Pre-Cenozoic Basement in Spring and Snake Valleys and Vicinity, Nevada and Utah

SNWA Exhibit 58

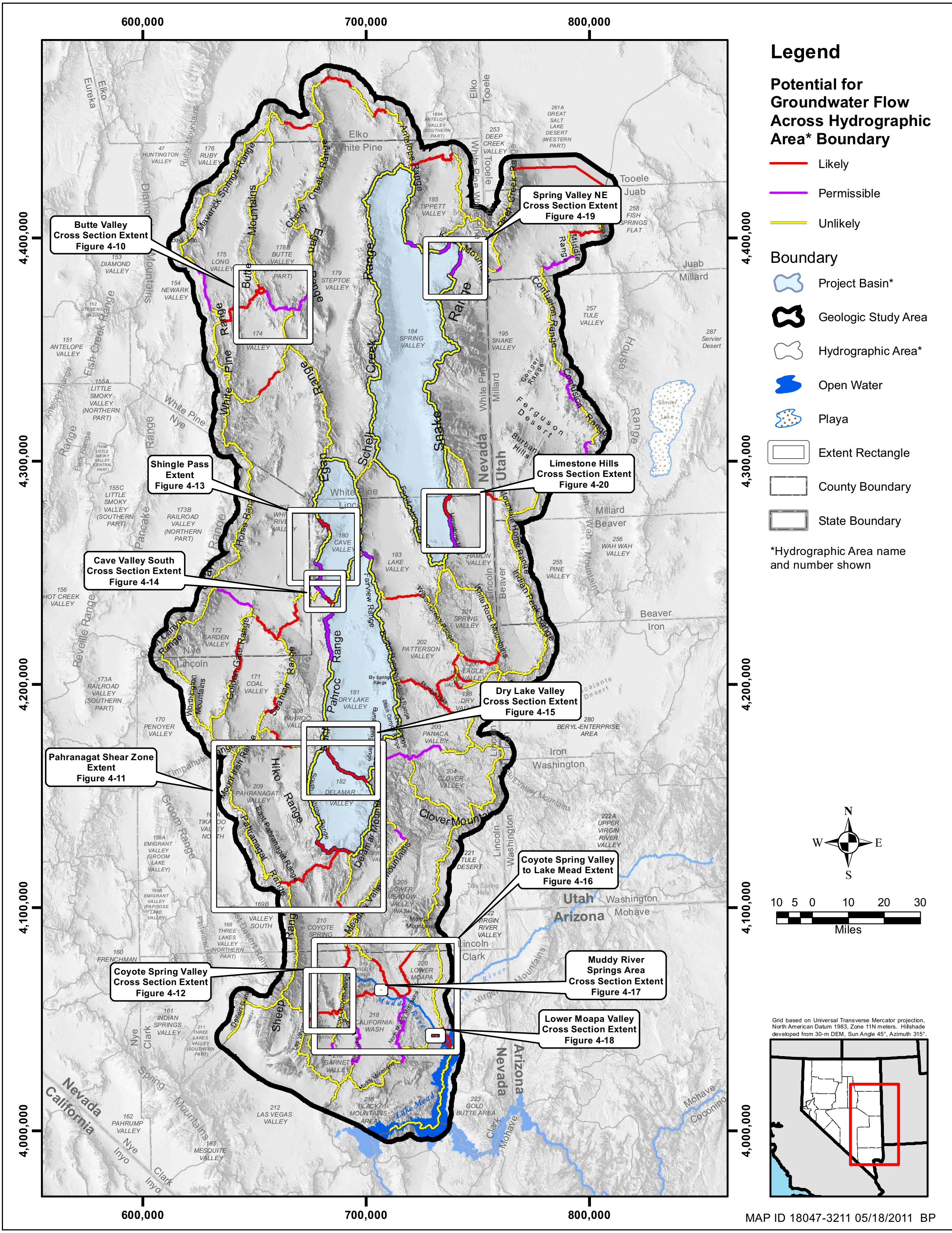


Figure 4-9

Potential for Interbasin Groundwater Flow within the Geologic Study Area

SNWA Exhibit 58

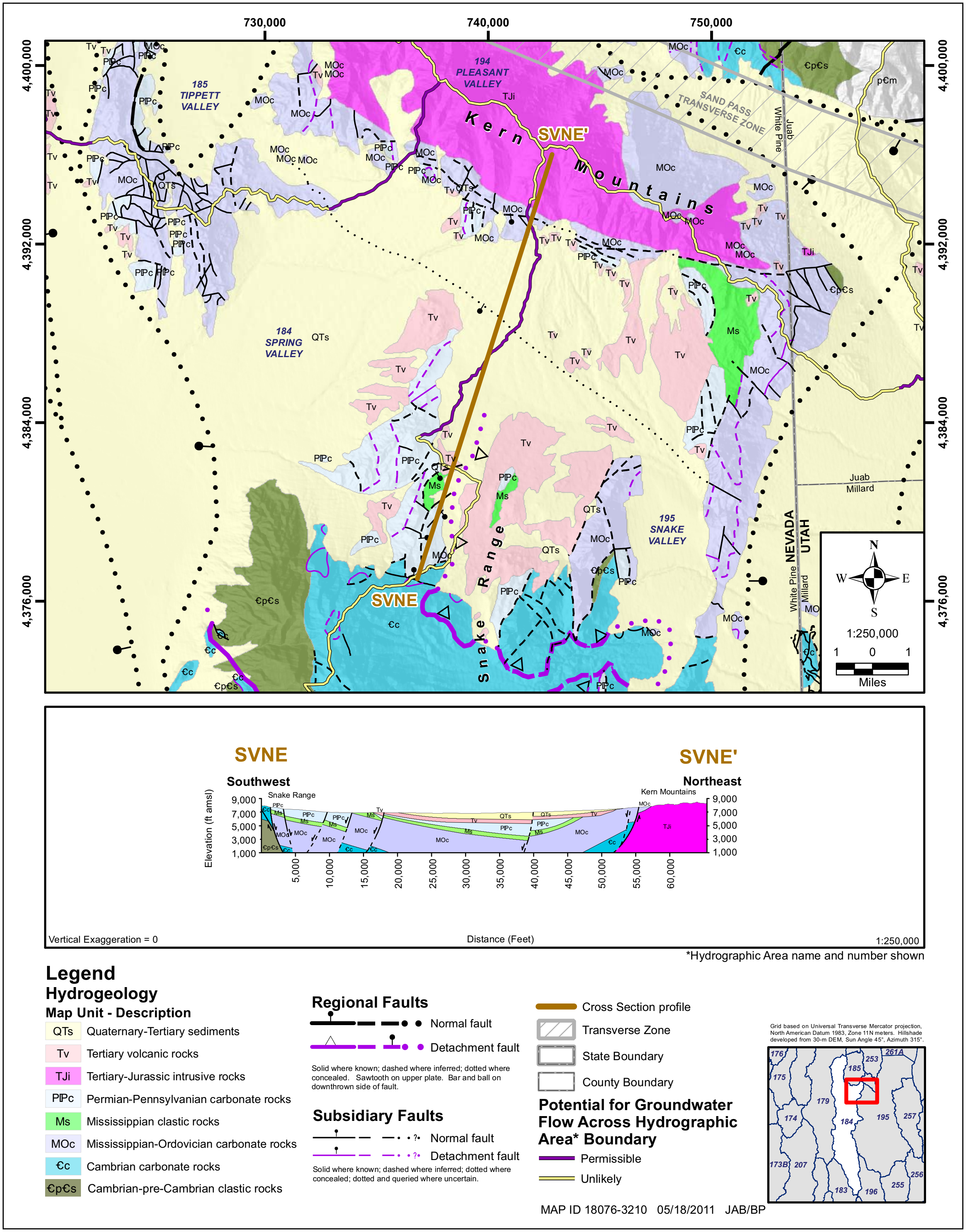
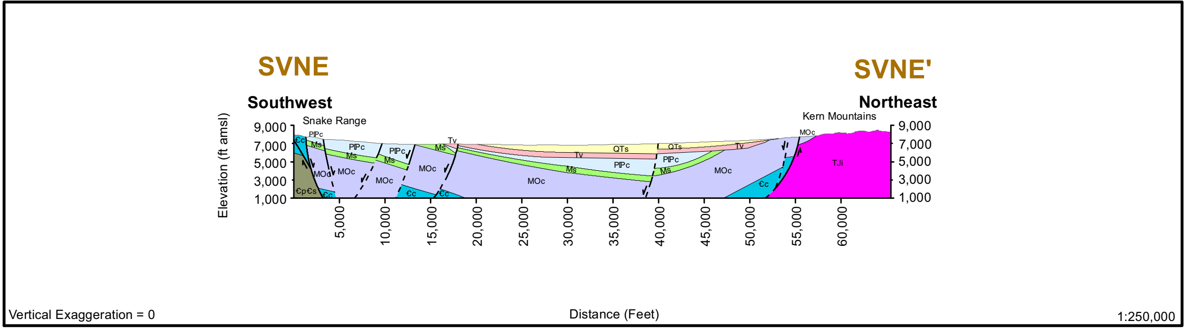
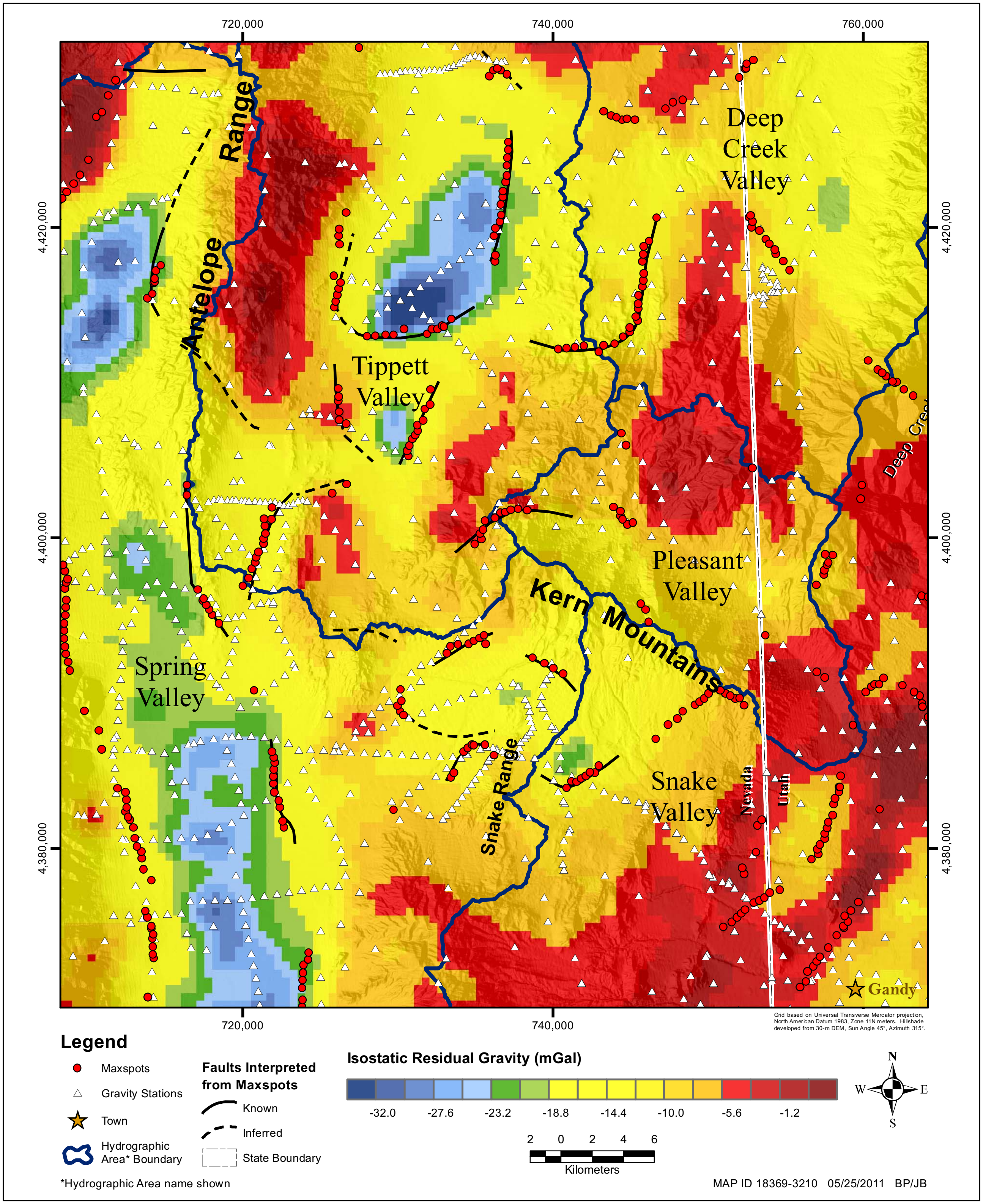


Figure 4-19
Hydrogeologic Map and Cross Section of Northeastern Spring Valley

SNWA Exhibit 58



*Hydrographic Area name and number shown



Note: Red maxspots are upward-continued from 3 km depth. Black lines are faults interpreted from maxspots.

Figure 5-6
Isostatic Residual Gravity Field and Maxspots in Tippett Valley, Western Kern Mountains, and Vicinity, Nevada

SNWA Exhibit 58

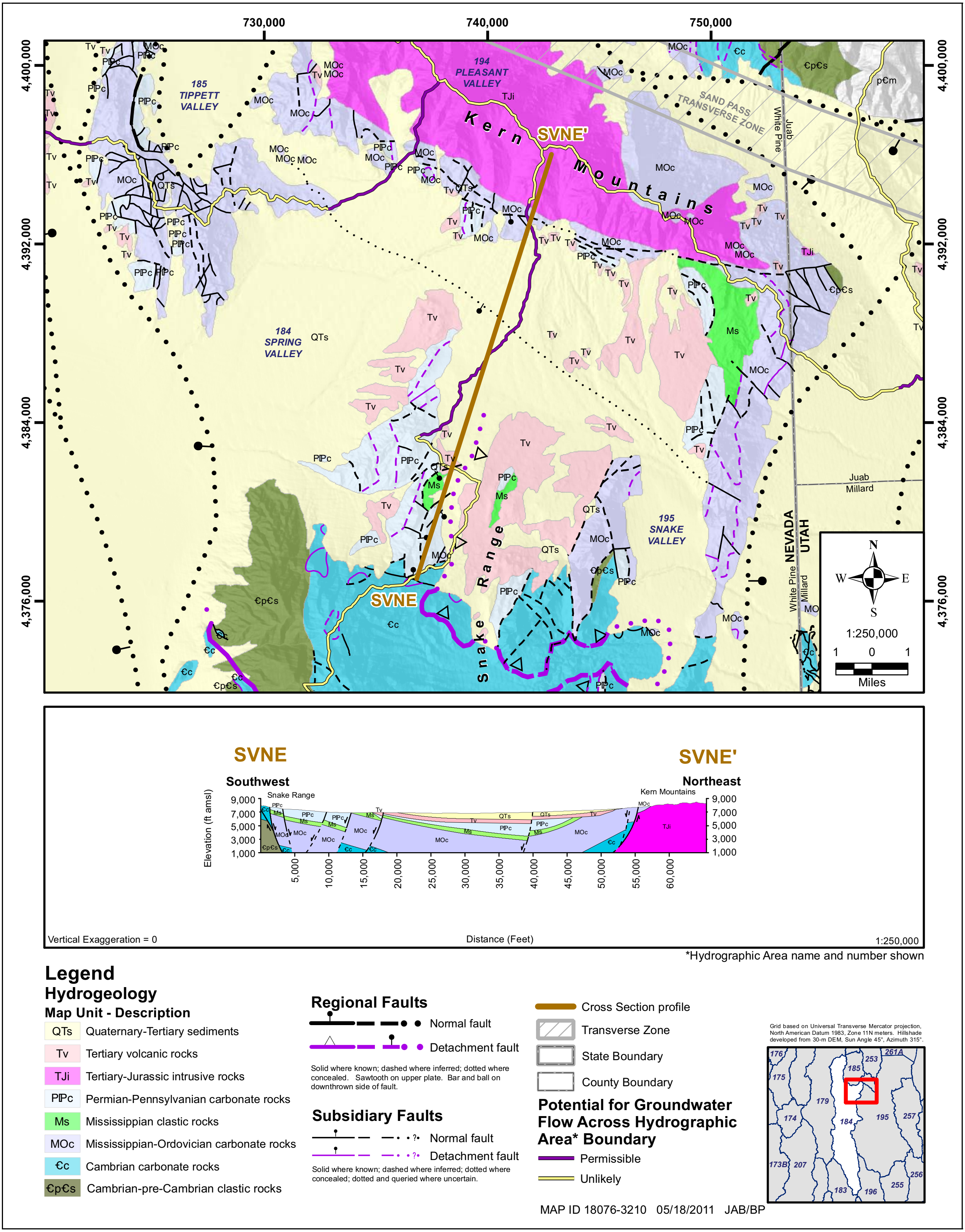


Figure 4-19
Hydrogeologic Map and Cross Section of Northeastern Spring Valley

SNWA Exhibit 58

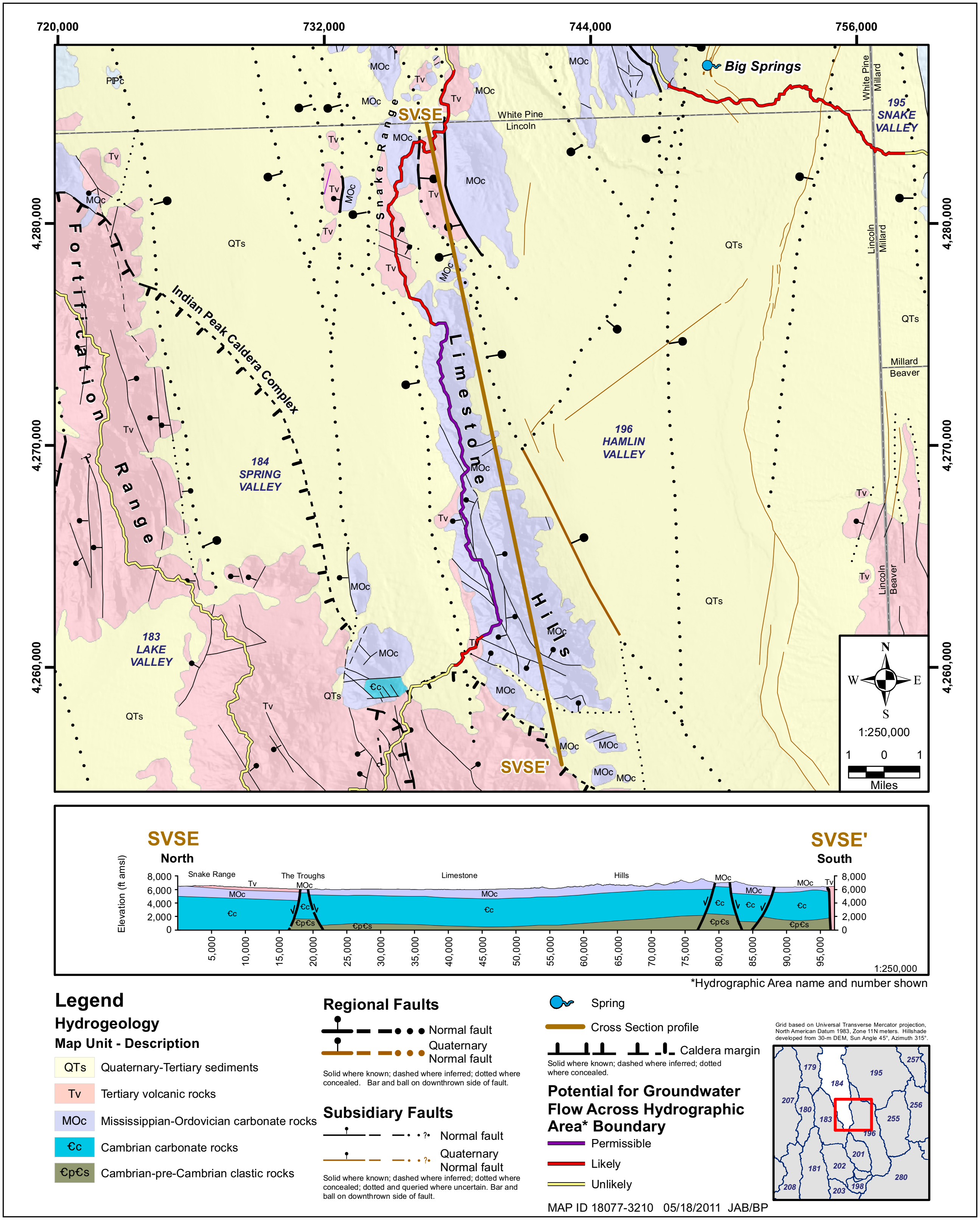
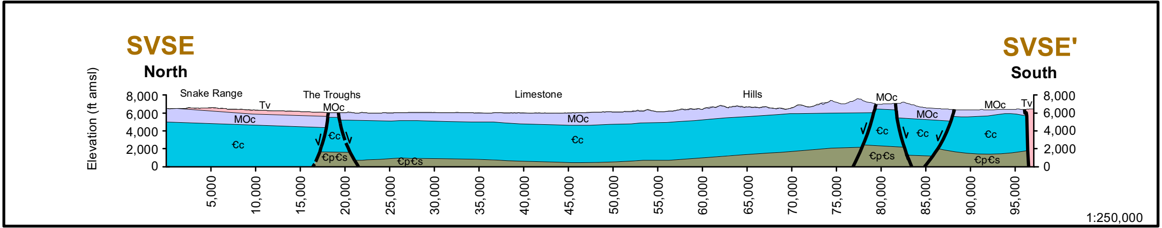


Figure 4-20
Hydrogeologic Map and Cross Section of the Southern Snake Range and Limestone Hills and Vicinity

SNWA Exhibit 58



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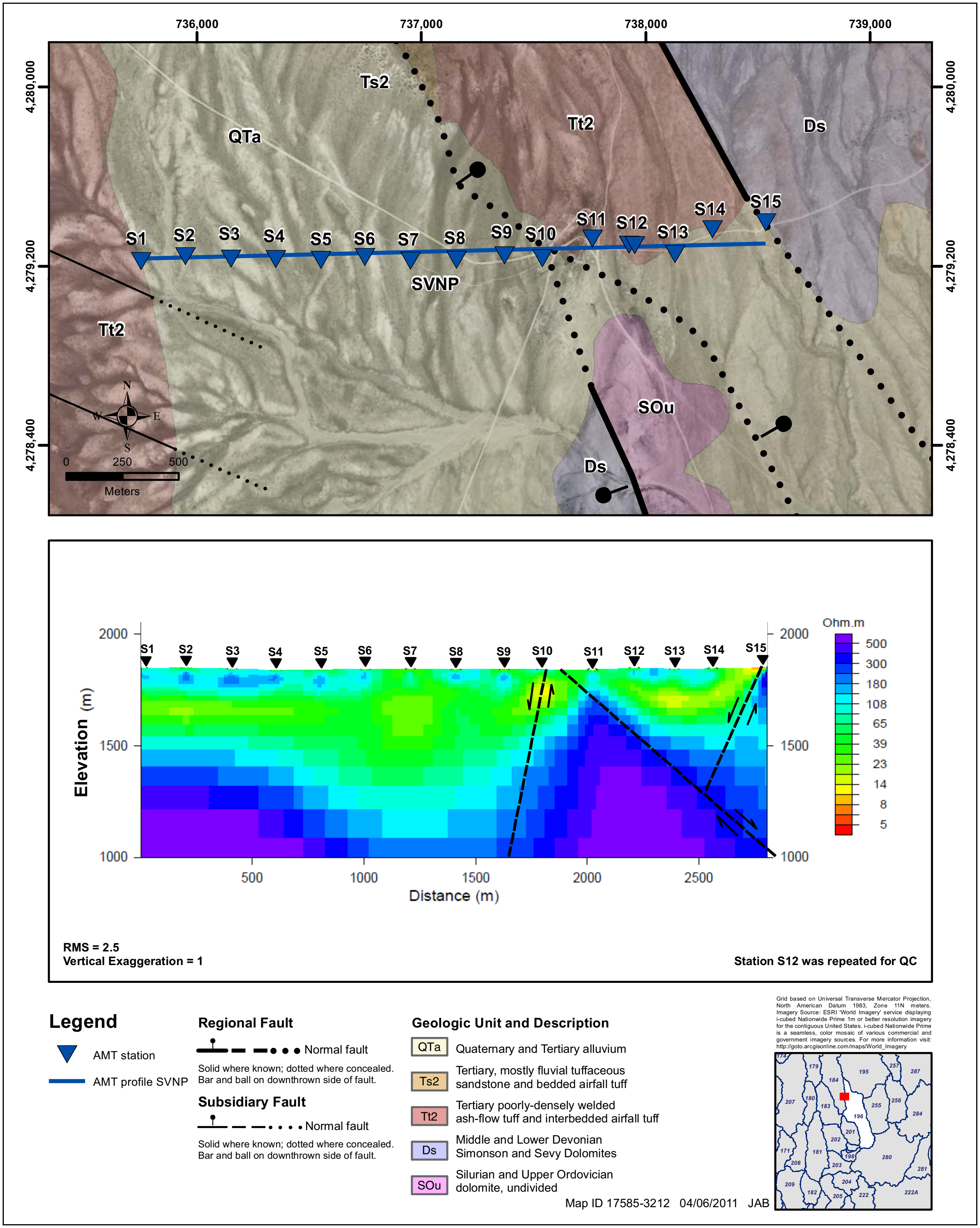
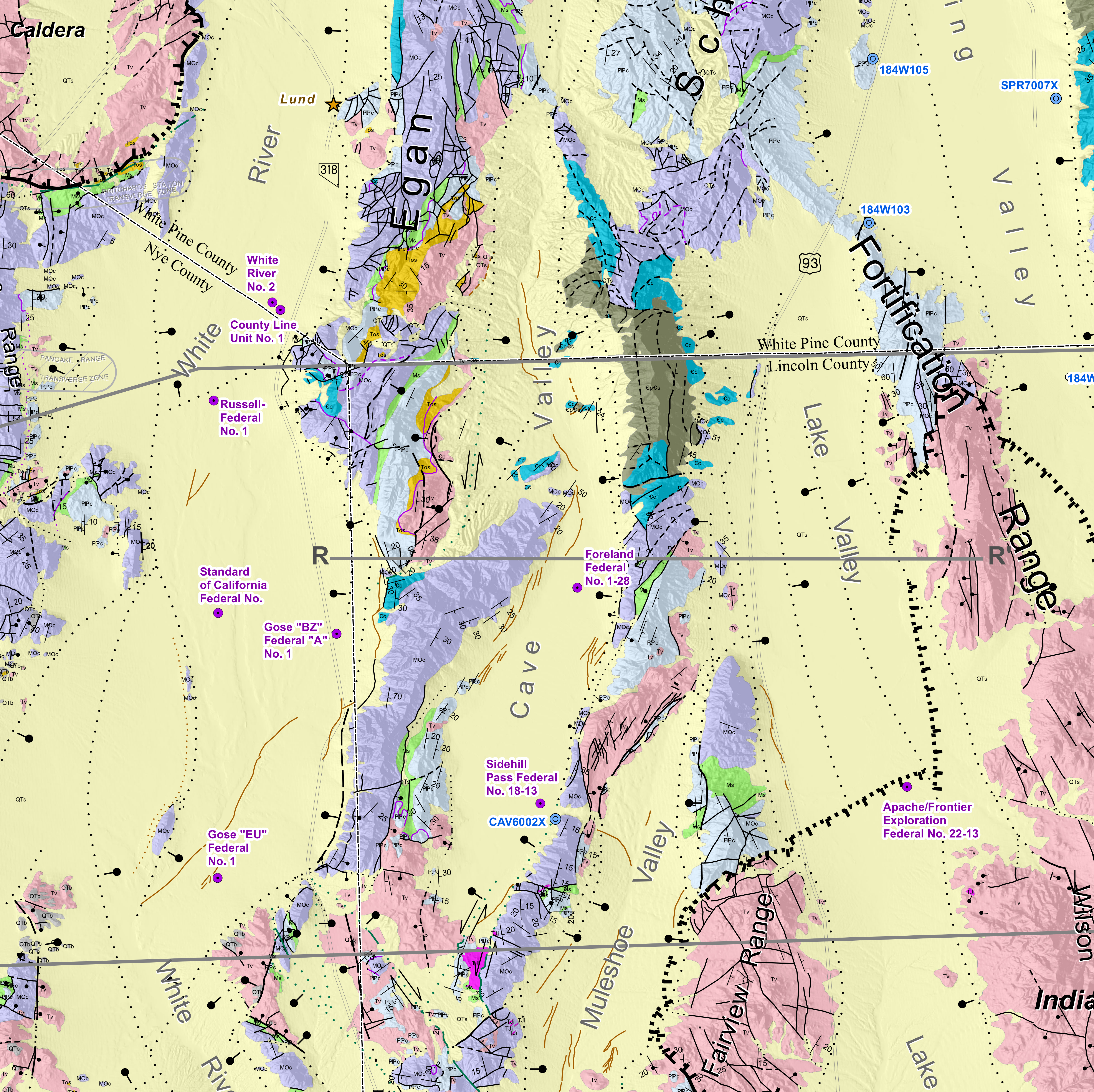
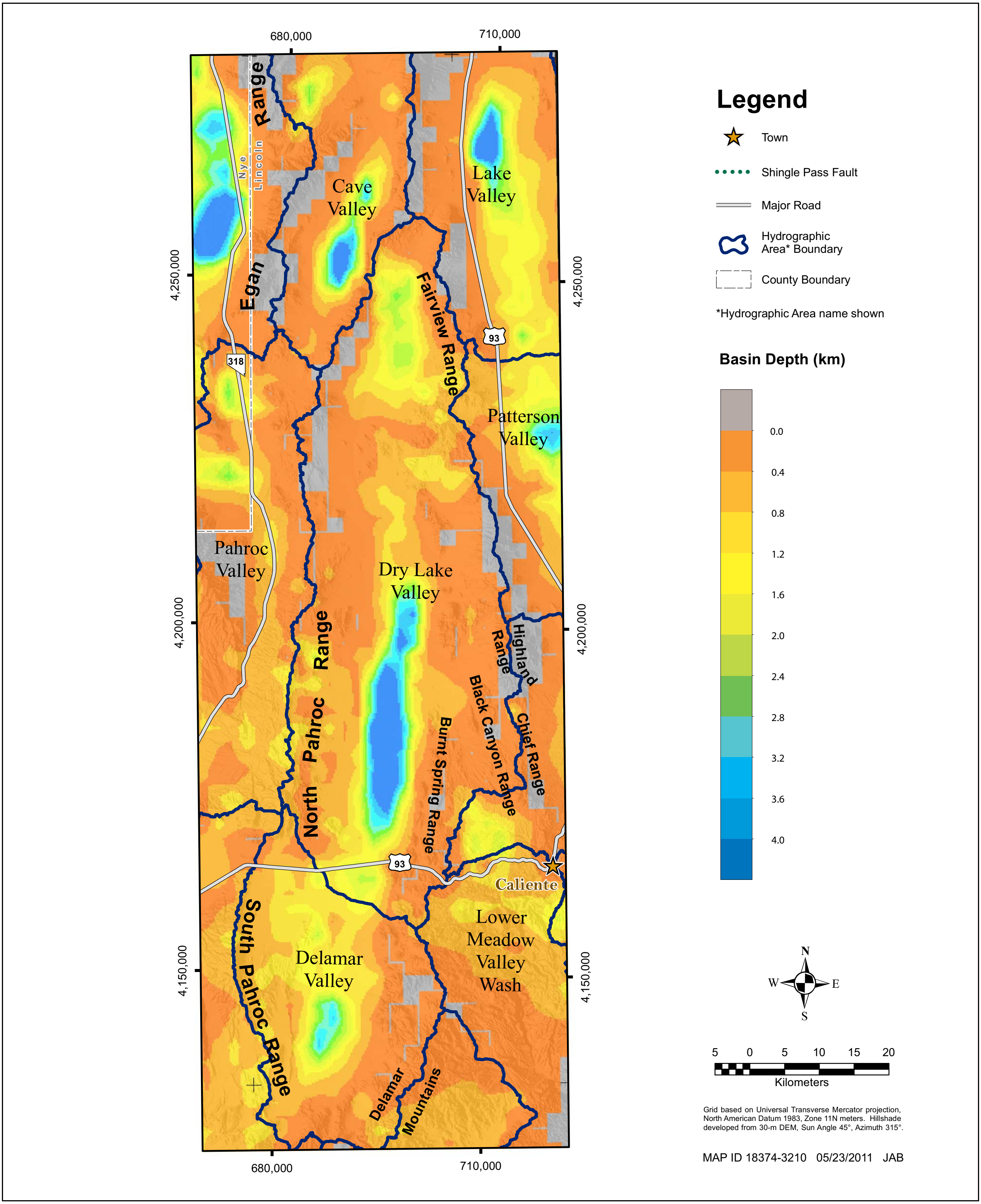


Source: Pari and Baird (2011)

Figure 5-20
Map and 2D Model of SVNP

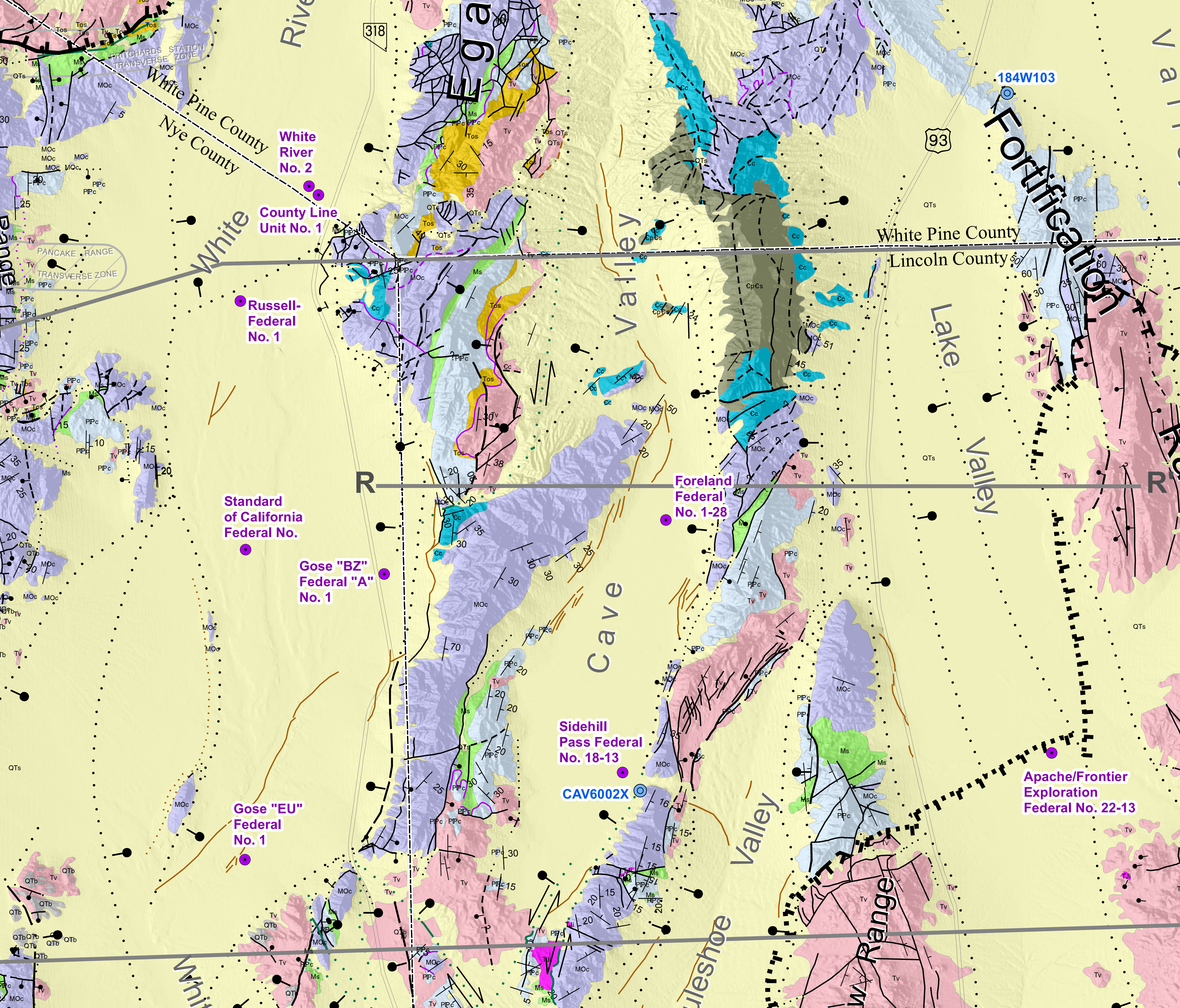


Caldera
Lund
318
White River No. 2
County Line Unit No. 1
Russell-Federal No. 1
Standard of California Federal No.
Gose "BZ" Federal "A" No. 1
Gose "EU" Federal No. 1
Sidehill Pass Federal No. 18-13
CAV6002X
Foreland Federal No. 1-28
Apache/Frontier Exploration Federal No. 22-13
184W105
SPR7007X
184W103
93
White Pine County
Nye County
Lincoln County
PRITCHARDS STATION TRANSVERSE ZONE
PANCAKE RANGE TRANSVERSE ZONE
White River
Egan
Cave Valley
Muleshoe Valley
Lake Valley
Fortification Range
Fairview Range
R
R'



Source: Mankinen et al. (2008)

Figure 5-13
Depth of pre-Cenozoic Basement of Cave, Dry Lake, and Delamar Valleys and Vicinity, Nevada



White Pine County
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Gose "EU" Federal No. 1
Foreland Federal No. 1-28
Sidehill Pass Federal No. 18-13
CAV6002X
184W103
Apache/Frontier Exploration Federal No. 22-13
White Pine County
Lincoln County
PANCAKE RANGE TRANSVERSE ZONE
PRITCHARDS STATION TRANSVERSE ZONE
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Egan
Cave Valley
Lake Valley
Fortification
Muleshoe Valley
Range
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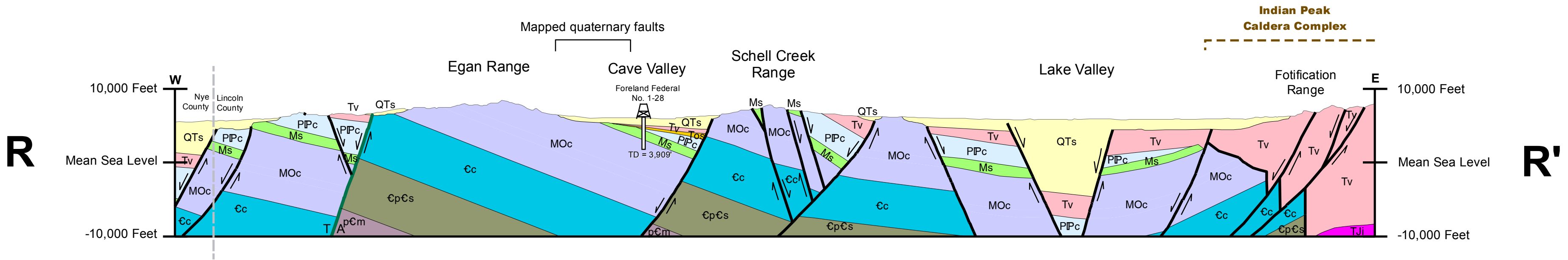
Mapped quaternary faults
Indian Peak
Caldera Complex
Egan Range
Cave Valley
Schell Creek
Range
Lake Valley
Fotification
Range
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Mean Sea Level
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Lincoln
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Foreland Federal
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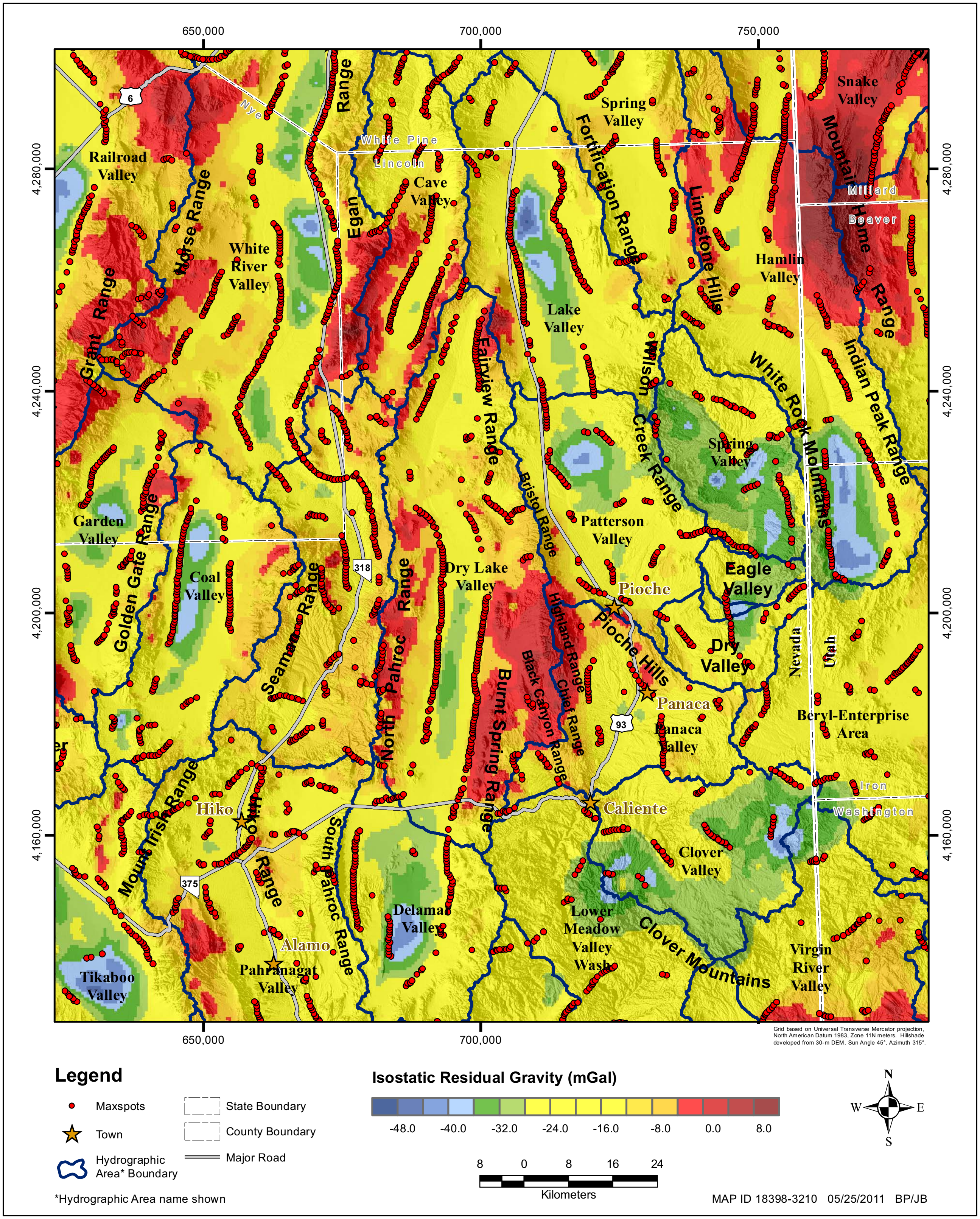
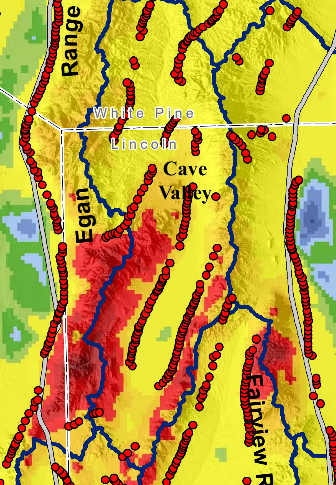
SECTION R - R'

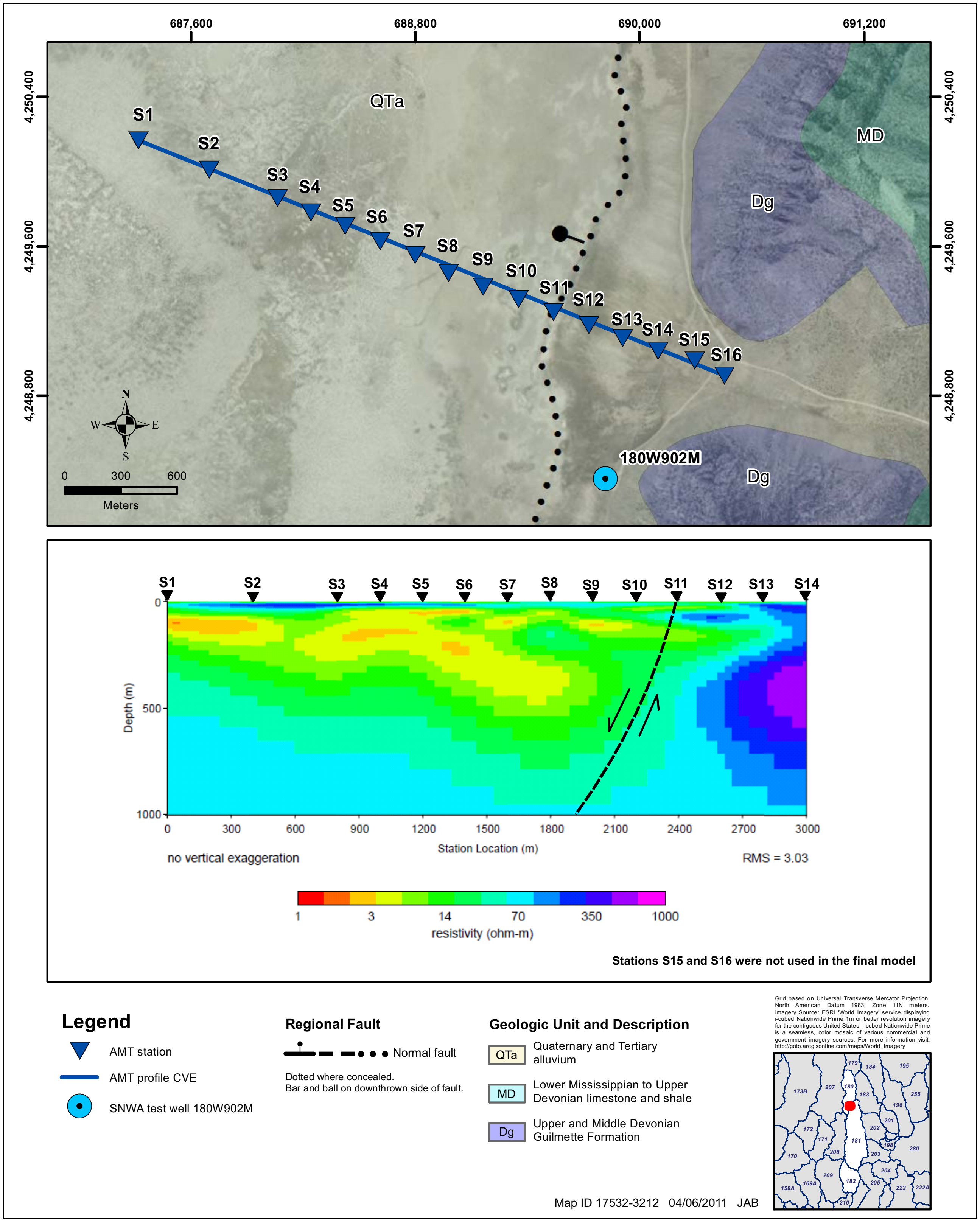


Source: Mankinen et al. (2008)

Figure 5-12
Isostatic Residual Gravity Field Showing Maxspots

SNWA Exhibit 58


Range
White Pine
Lincoln
Cave
Valley
Egan
Fairview R



Source: Pari and Baird (2011)

Figure 5-23
Map and 2D Model of CVE

SNWA Exhibit 58

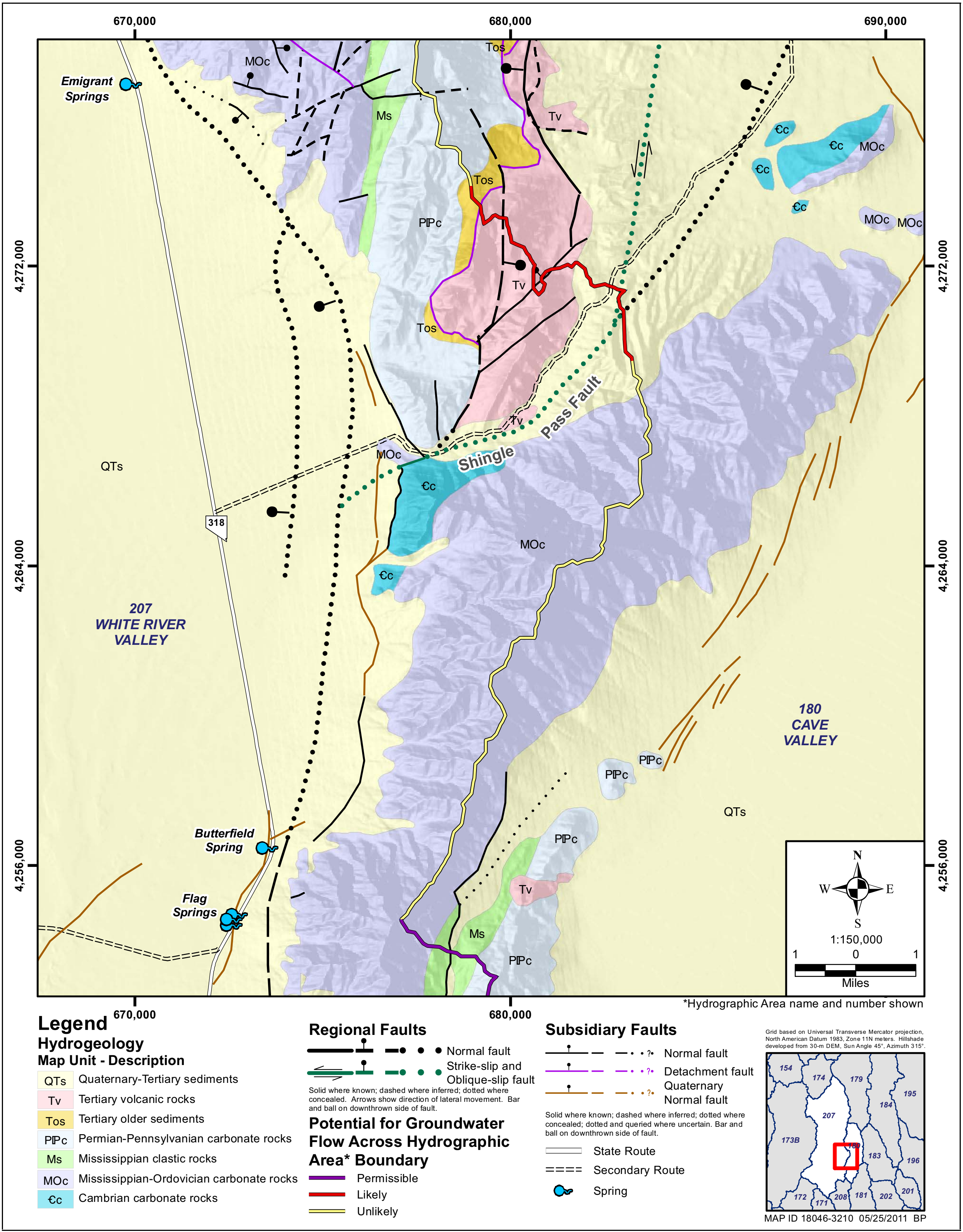


Figure 4-13
Hydrogeologic Map and Basin Boundaries of Shingle Pass Area

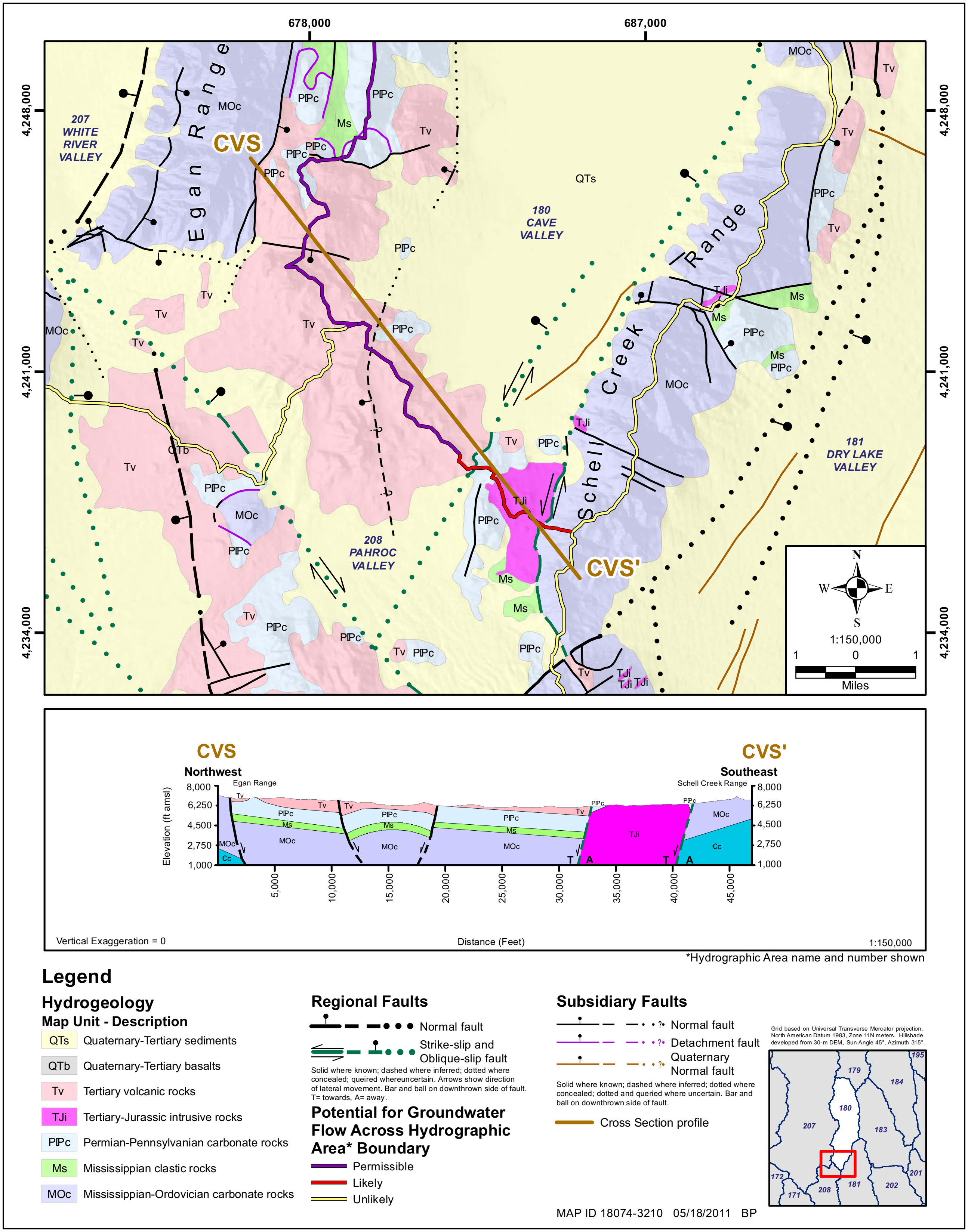
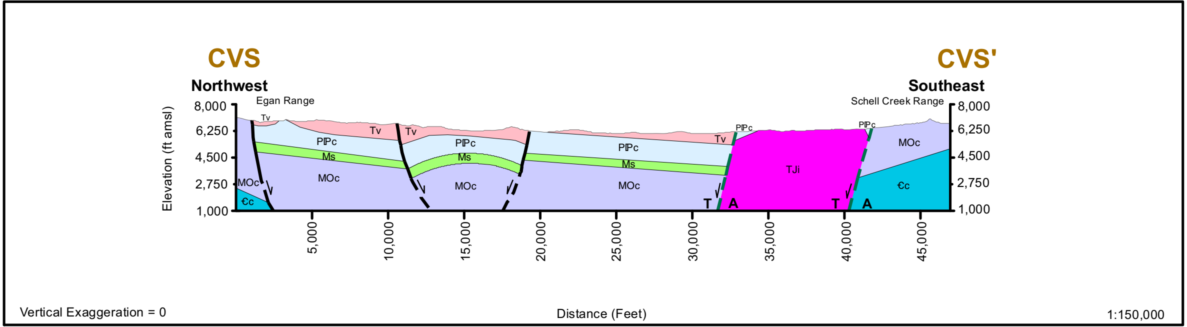
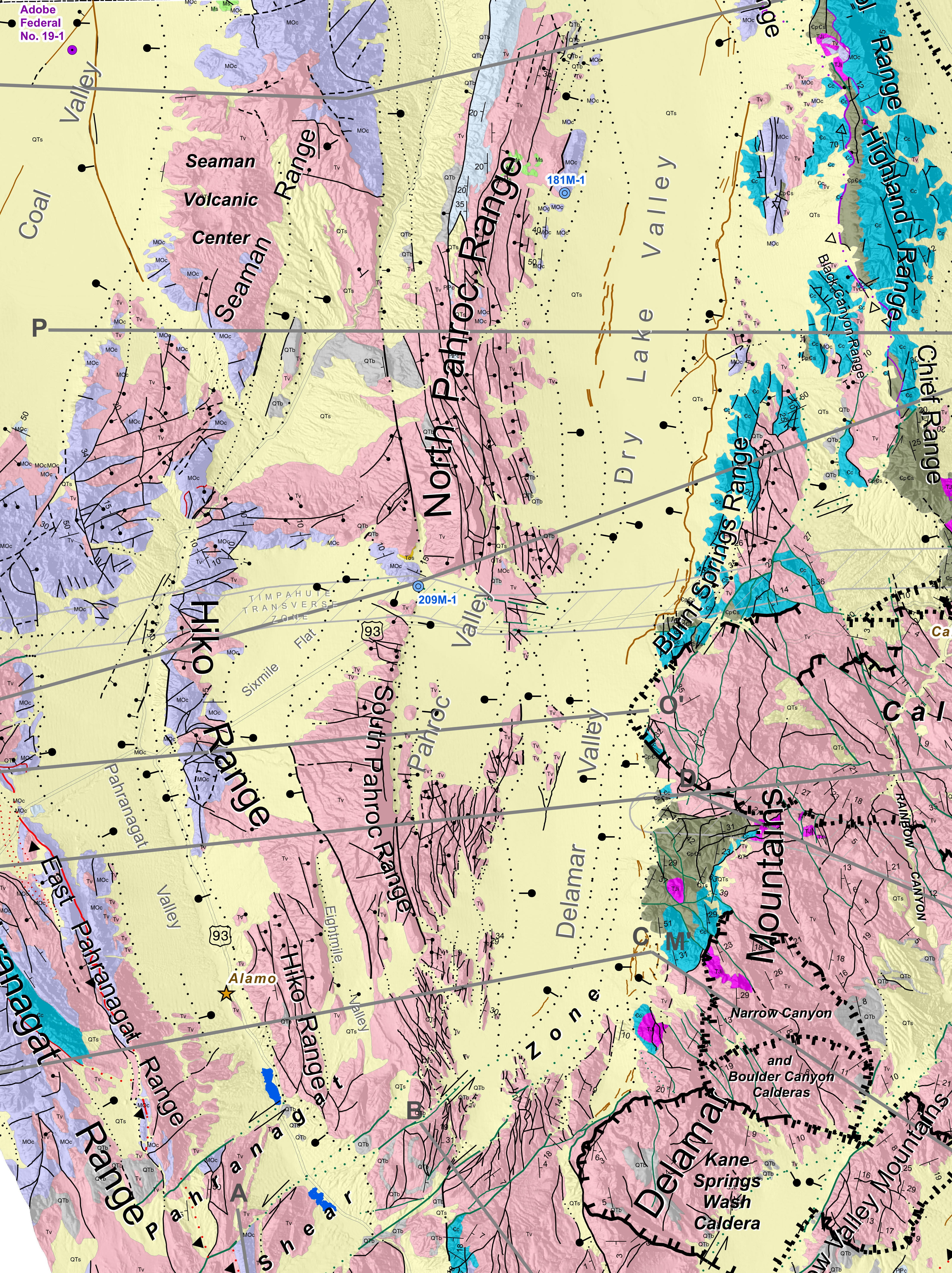


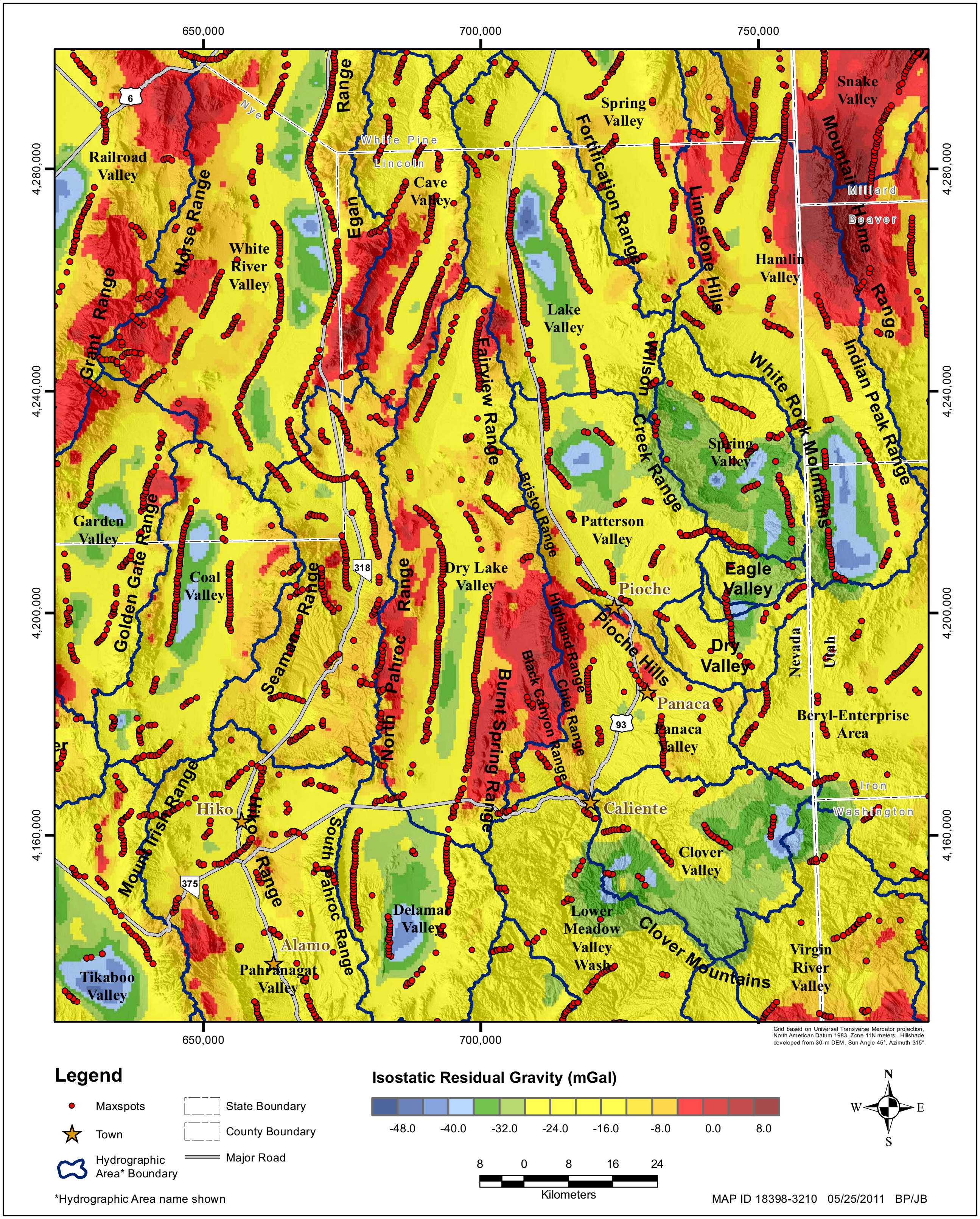
Figure 4-14
Hydrogeologic Map and Cross Section of Southern Cave Valley and Vicinity

SNWA Exhibit 58



*Hydrographic Area name and number shown


Adobe Federal No. 19-1
Coal Valley
Seaman Volcanic Center
Seaman Range
North Pahroc Range
181M-1
Dry Lake Valley
Highland Range
Black Canyon Range
Chief Range
Burnt Springs Range
P
TIMPAHUTE TRANSVERSE ZONE
209M-1
Sixmile Flat
93
Pahroc Valley
Hiko Range
South Pahroc Range
Delamar Valley
O'
D
Mountains
RAINBOW CANYON
Pahranagat Valley
East Pahranagat Range
Eightmile Valley
C
M
Alamo
Narrow Canyon and Boulder Canyon Calderas
Pahranagat Shear Zone
B
A
Delamar
Kane Springs Wash Caldera
Range
Meadow Valley Mountains



Source: Mankinen et al. (2008)

Figure 5-12
Isostatic Residual Gravity Field Showing Maxspots

SNWA Exhibit 58

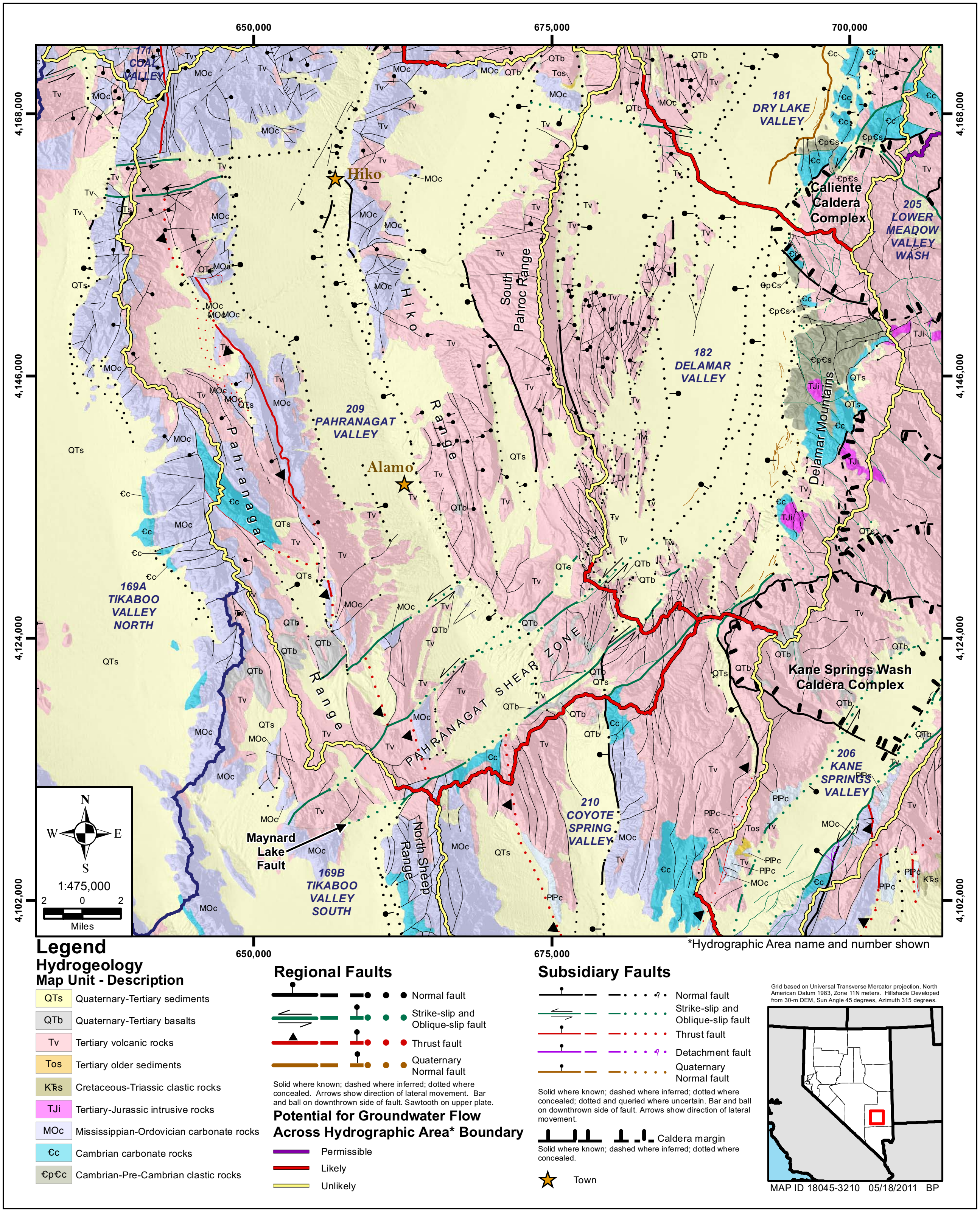


Figure 4-11
Hydrogeologic Map and Basin Boundaries of Pahranagat and Delamar Valleys and Vicinity

SNWA Exhibit 58

Volume 3

Physical Settings of Selected Springs in Clark, Lincoln, and White Pine Counties Groundwater Development Project

January 2008

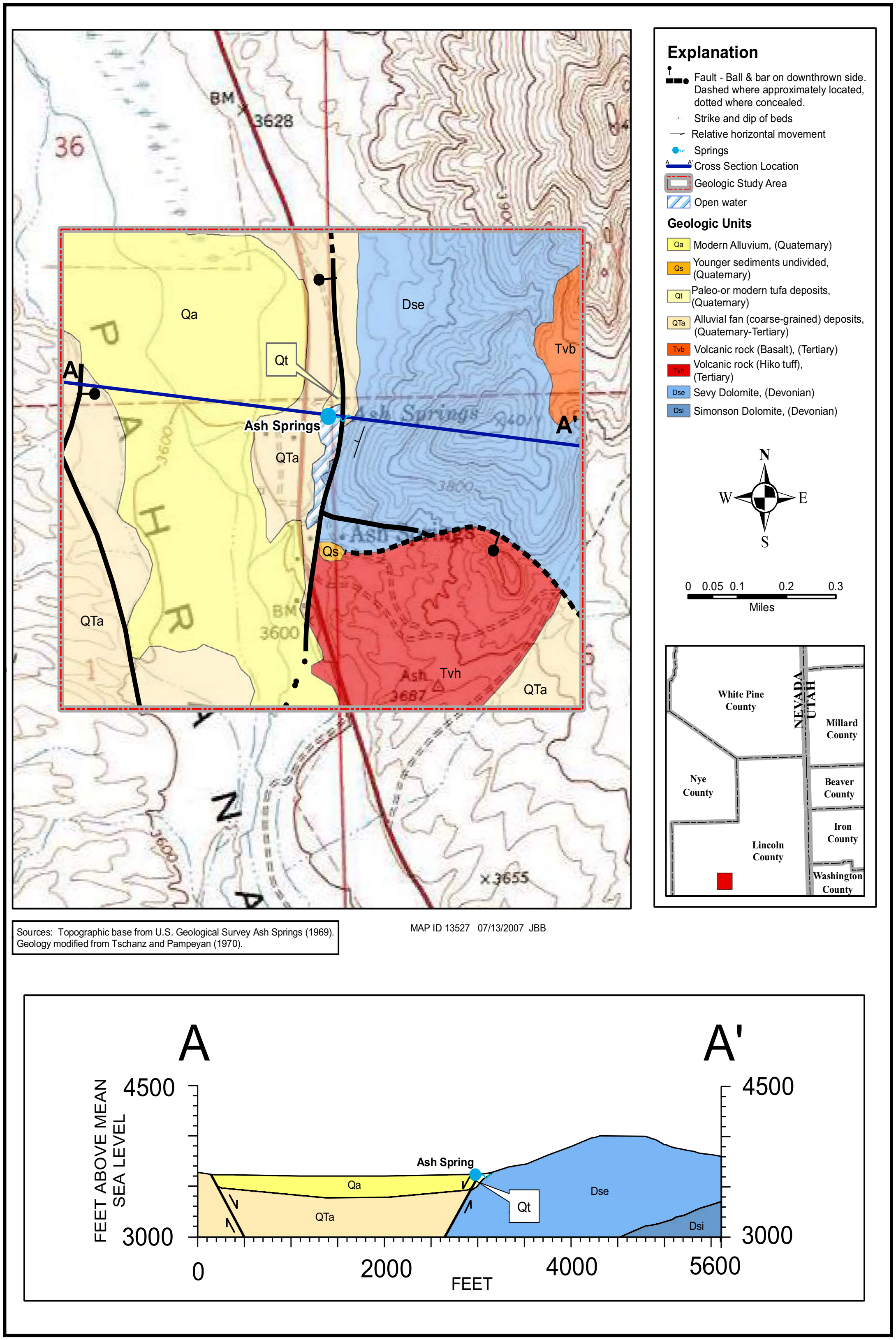
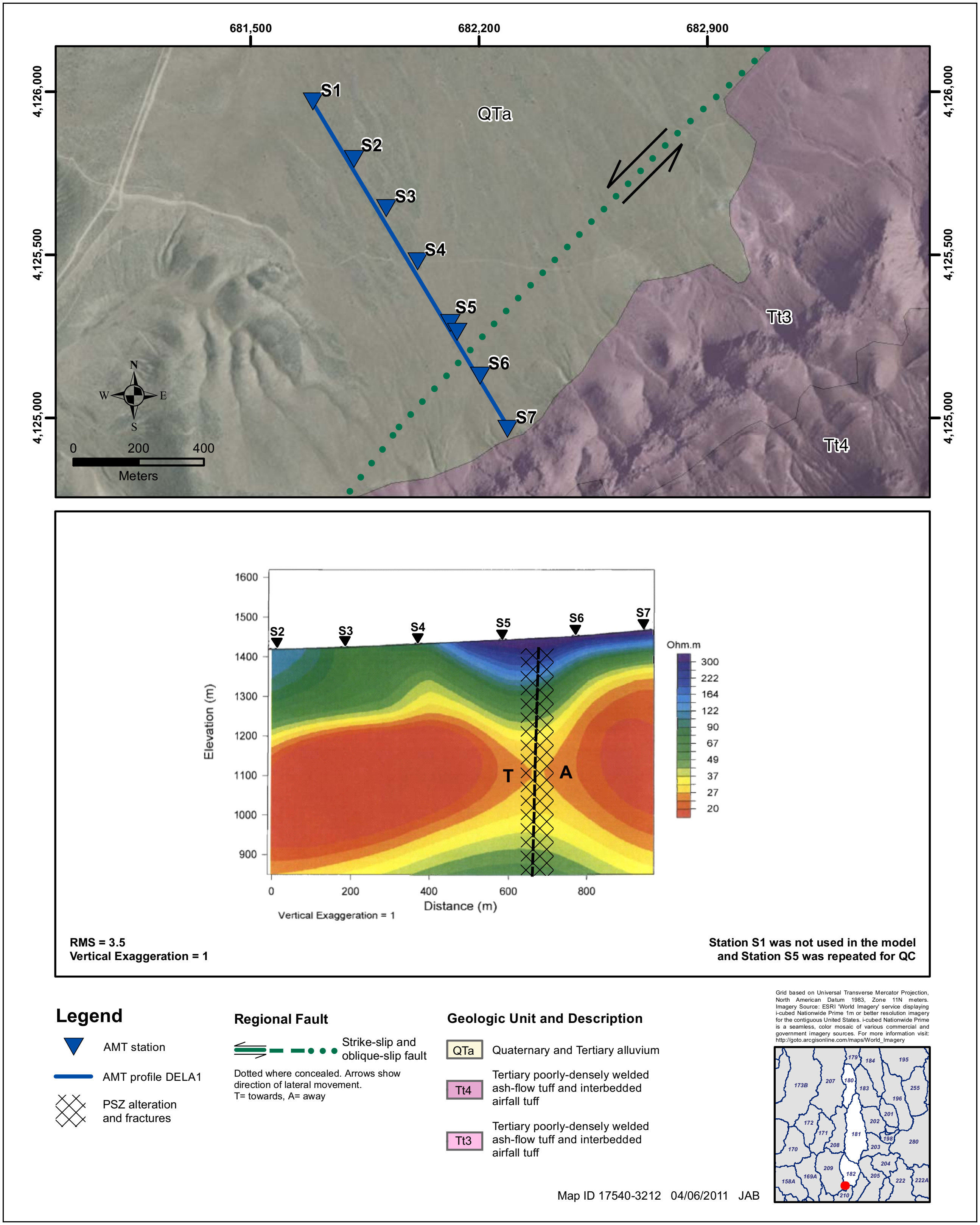


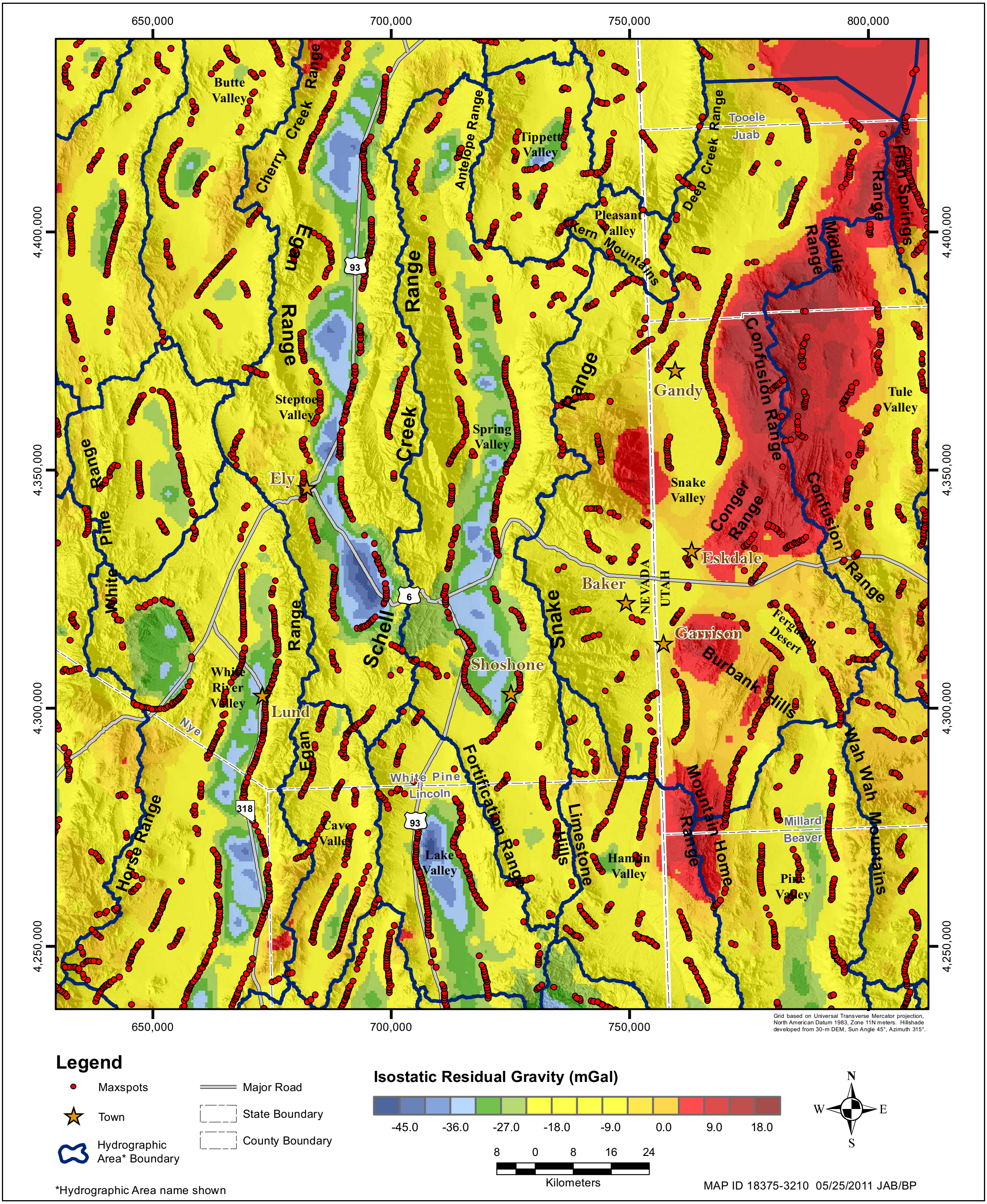
Figure 3-71
Geologic Map and Cross Section of Ash Springs, Lincoln County, Nevada

SNWA Exhibit 70



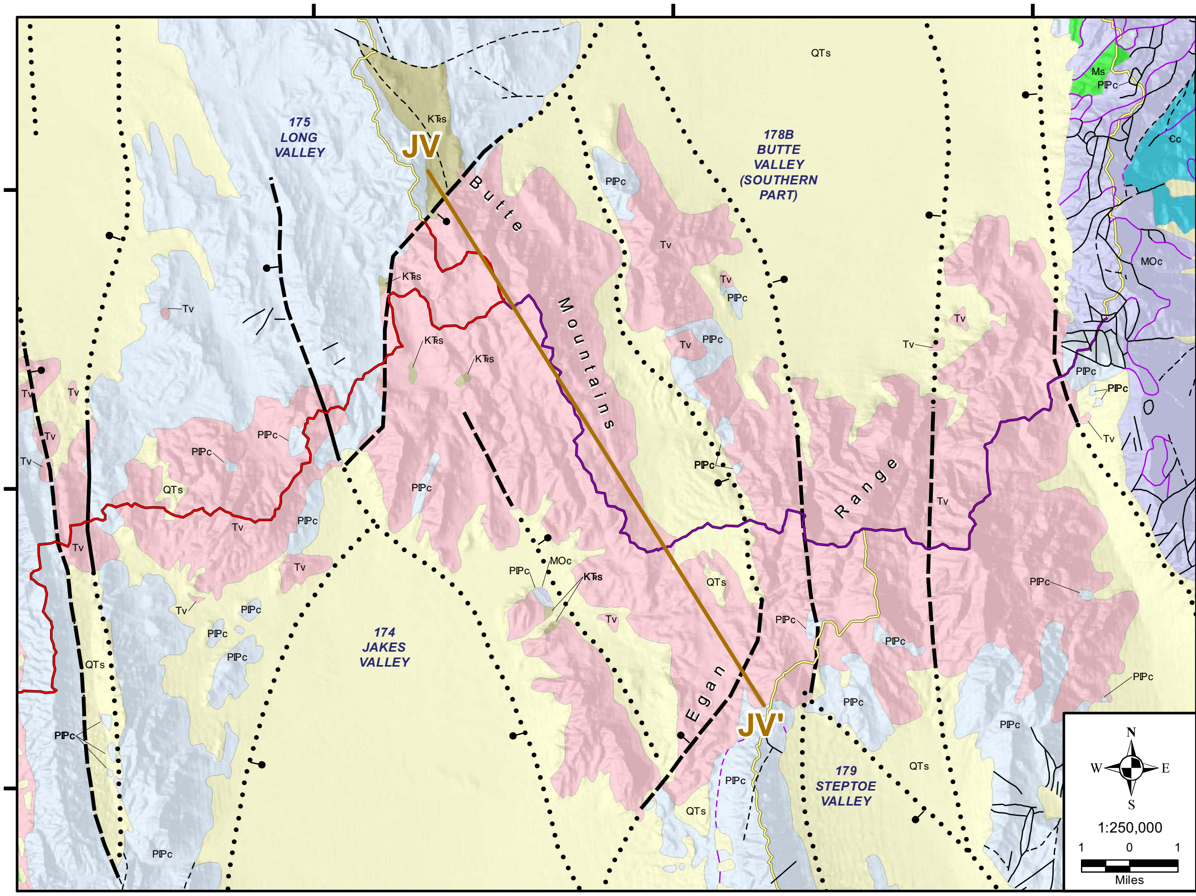
Source: Pari and Baird (2011)

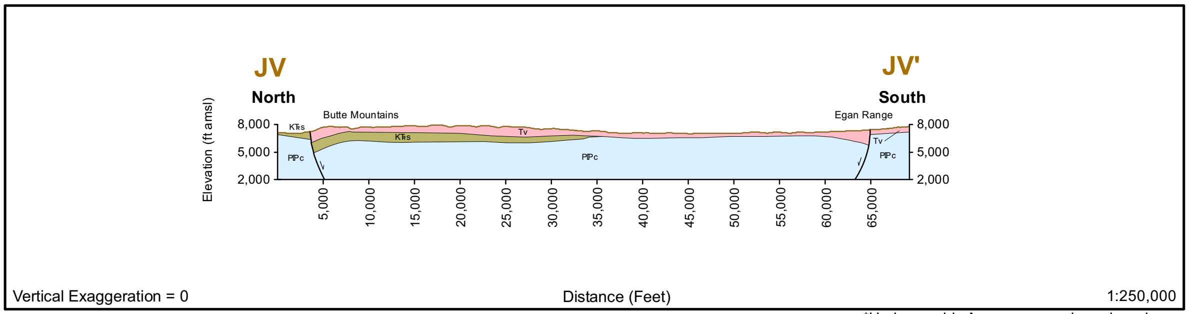
Figure 5-28
Map and 2D Model of DELA1



Note: Maxspots calculated from the 3-km upward-continued gravity grid.

Figure 5-4
Isostatic Residual Gravity Field and Maxspots in Spring and Snake Valleys and Vicinity, Nevada and Utah





*Hydrographic Area name and number shown

Legend

Hydrogeology

Map Unit - Description

- QTs — Quaternary-Tertiary sediments
- Tv — Tertiary volcanic rocks
- KTRs — Cretaceous-Triassic clastic rocks
- PIPc — Permian-Pennsylvanian carbonate rocks
- Ms — Mississippian clastic rocks
- MOc — Mississippian-Ordovician carbonate rocks

Regional Faults

Normal fault

Solid where known; dashed where inferred; dotted where concealed. Bar and ball on downthrown side of fault.

Subsidiary Faults

Normal fault

Detachment fault

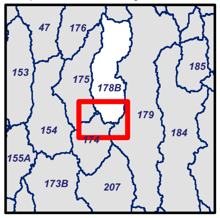
Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Bar and ball on downthrown side of fault.

Cross Section profile

Potential for Groundwater Flow Across Hydrographic Area* Boundary

- Permissible
- Likely
- Unlikely

Grid based on Universal Transverse Mercator projection, North American Datum 1983, Zone 11N meters. Hillshade developed from 30-m DEM, Sun Angle 45°, Azimuth 315°.

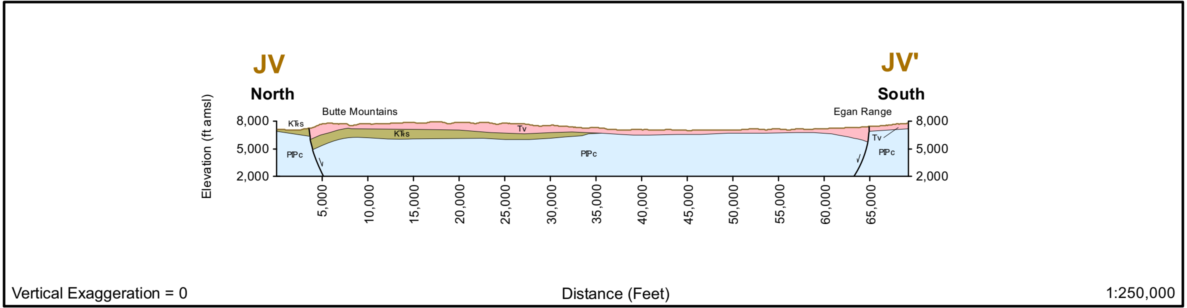


MAP ID 18073-3210 05/25/2011 BP

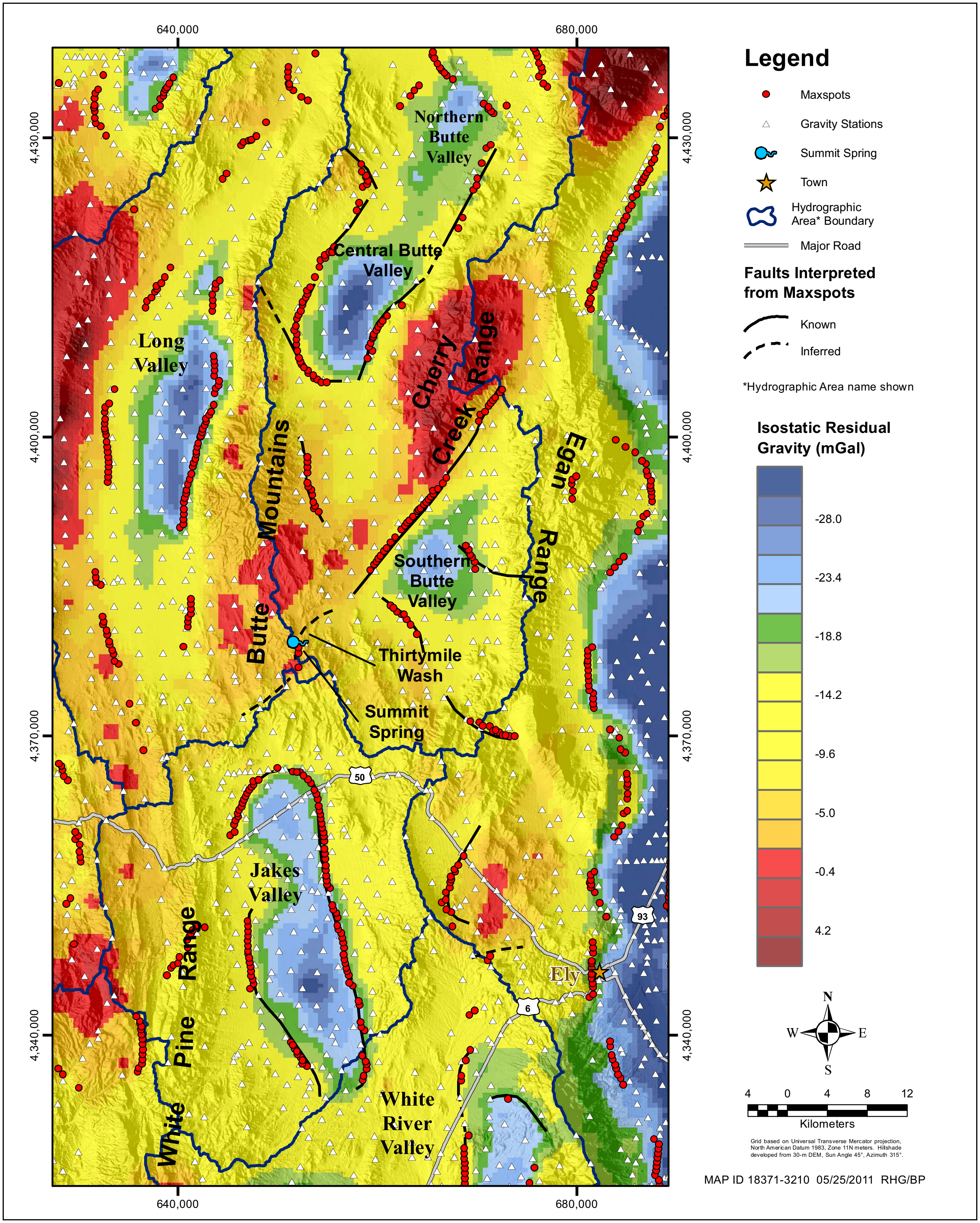
Figure 4-10

Hydrogeologic Map and Cross Section of Area between Butte Valley and Jakes Valley

SNWA Exhibit 58



*Hydrographic Area name and number shown



Note: Red maxspots are upward-continued from 3 km depth. Black lines are faults interpreted from maxspots.

Figure 5-8
Isostatic Residual Gravity Field in Butte and Jakes Valleys and Vicinity, Nevada

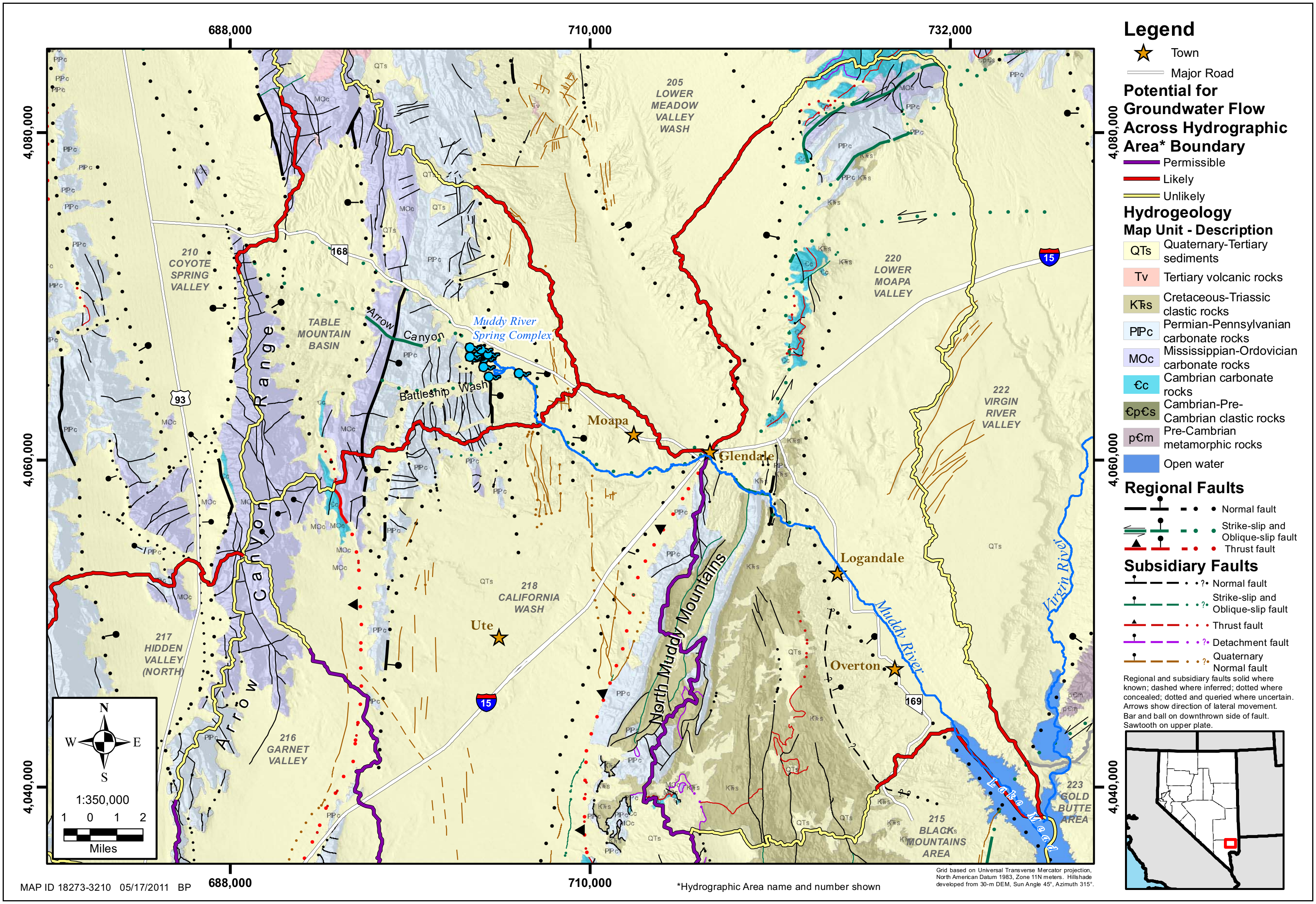


Figure 4-16
Hydrogeologic Map of Coyote Spring Valley to Lake Mead

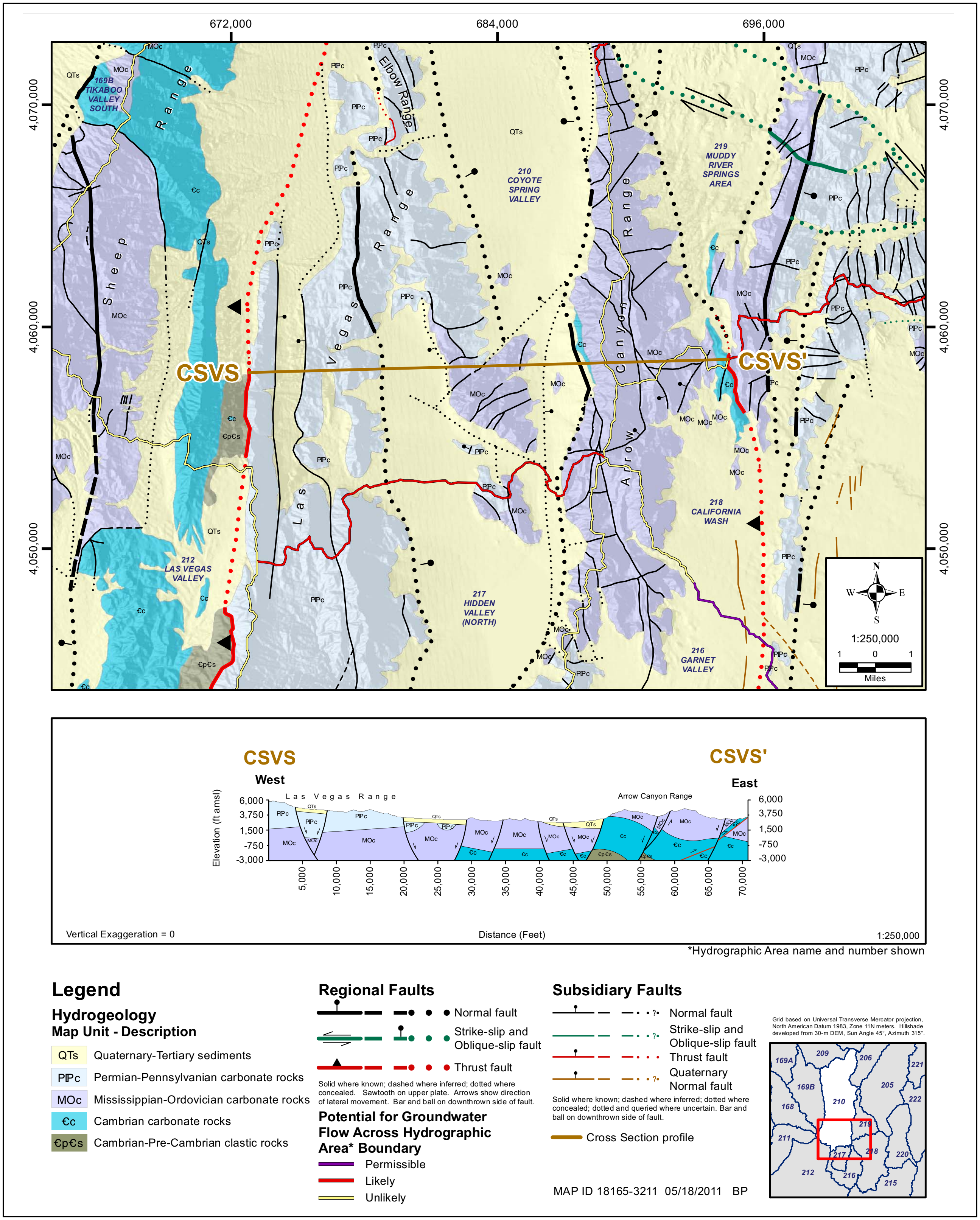
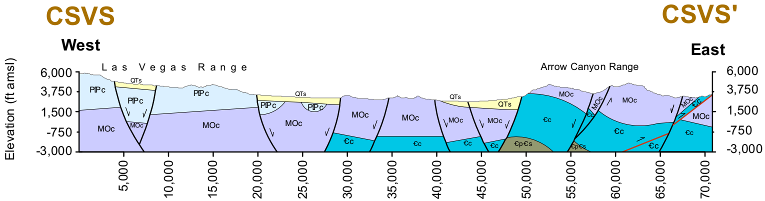


Figure 4-12
Hydrogeologic Map and Cross Section of Southern Coyote Spring Valley and Hidden Valley

SNWA Exhibit 58



Vertical Exaggeration = 0

Distance (Feet)

1:250,000

*Hydrographic Area name and number shown

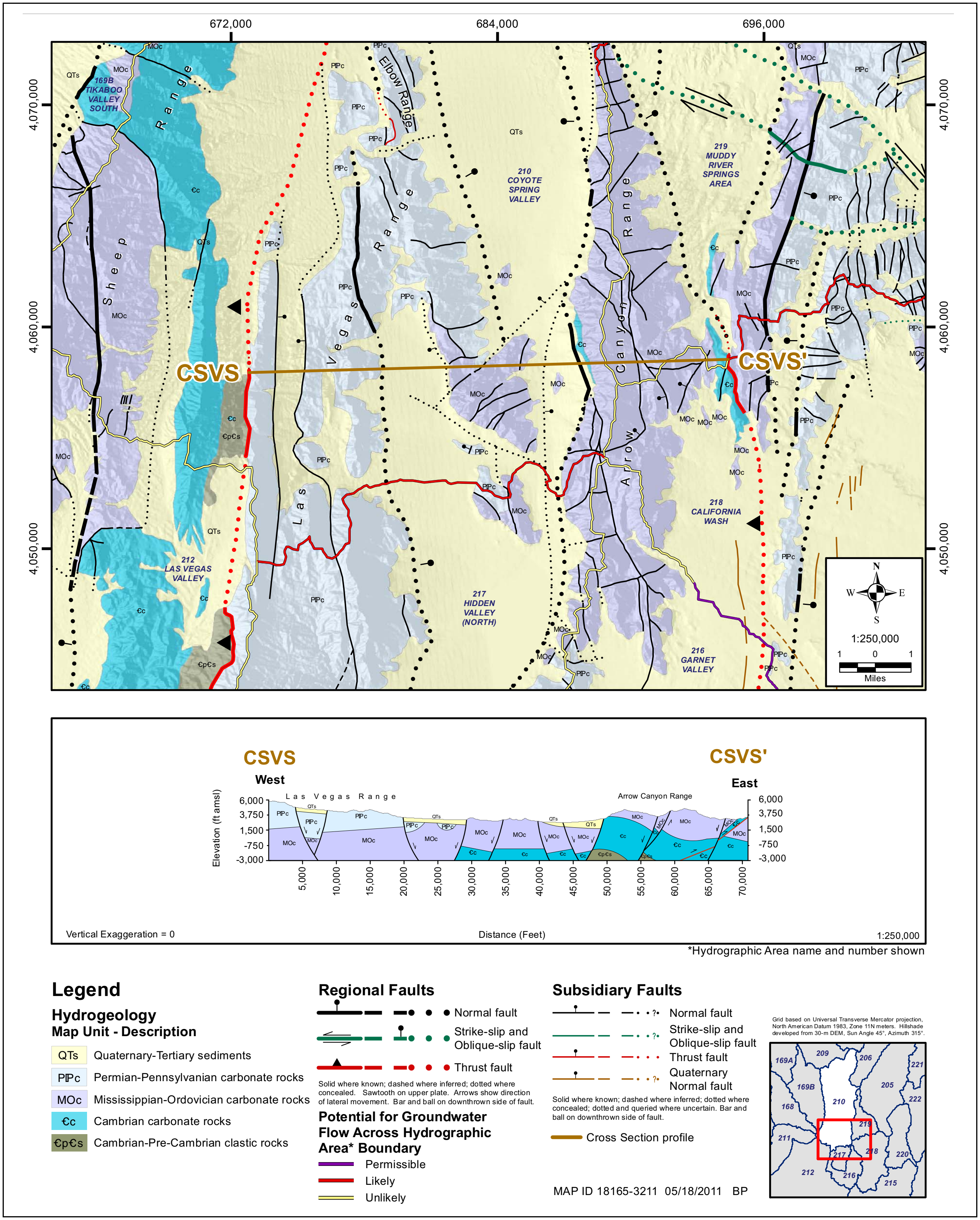


Figure 4-12
Hydrogeologic Map and Cross Section of Southern Coyote Spring Valley and Hidden Valley

SNWA Exhibit 58

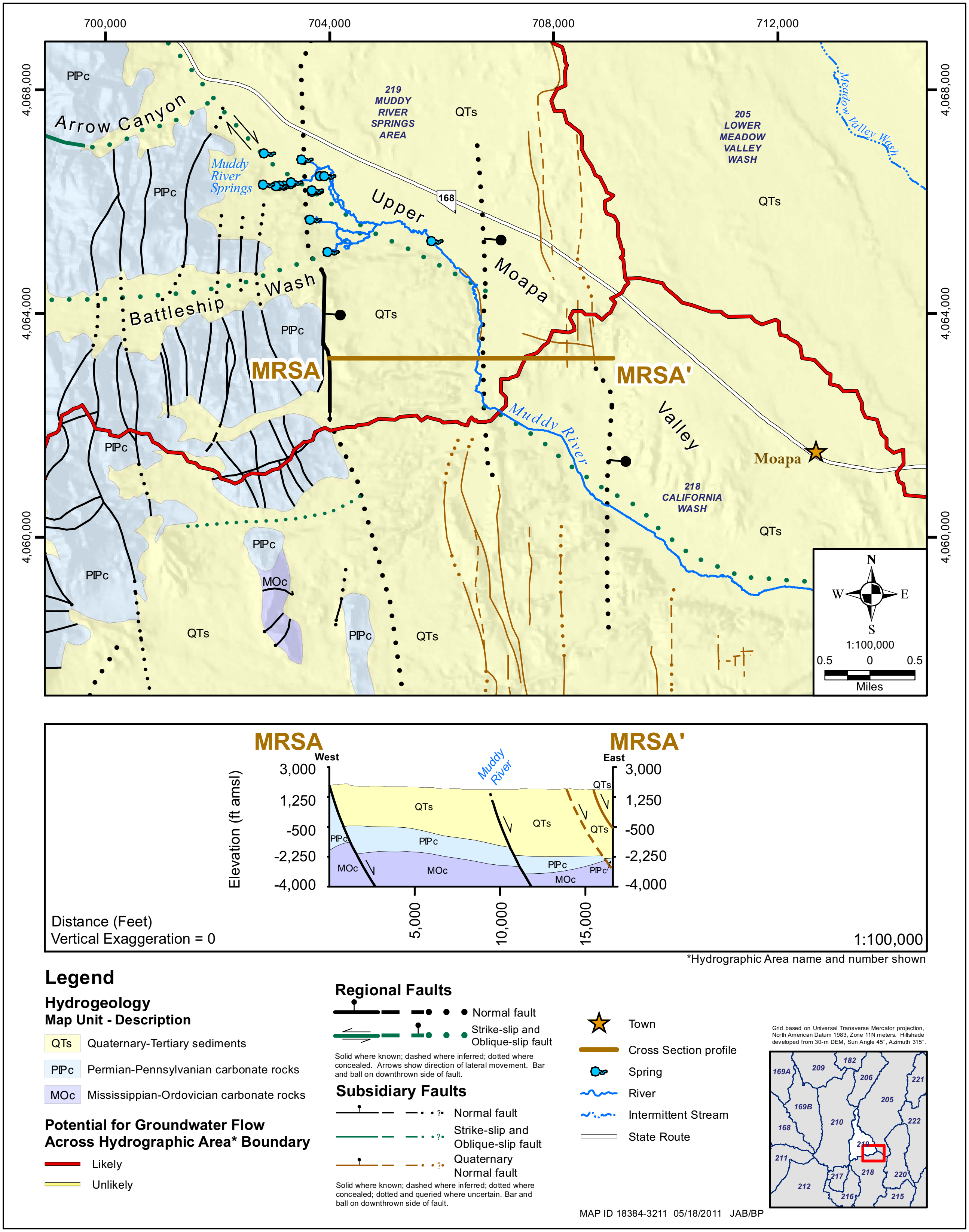
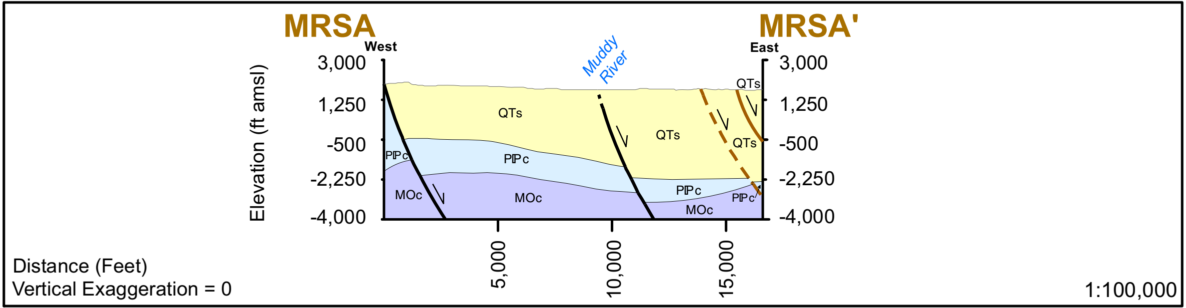


Figure 4-17
Hydrogeologic Map and Cross Section of the Muddy River Springs Area

SNWA Exhibit 58



*Hydrographic Area name and number shown

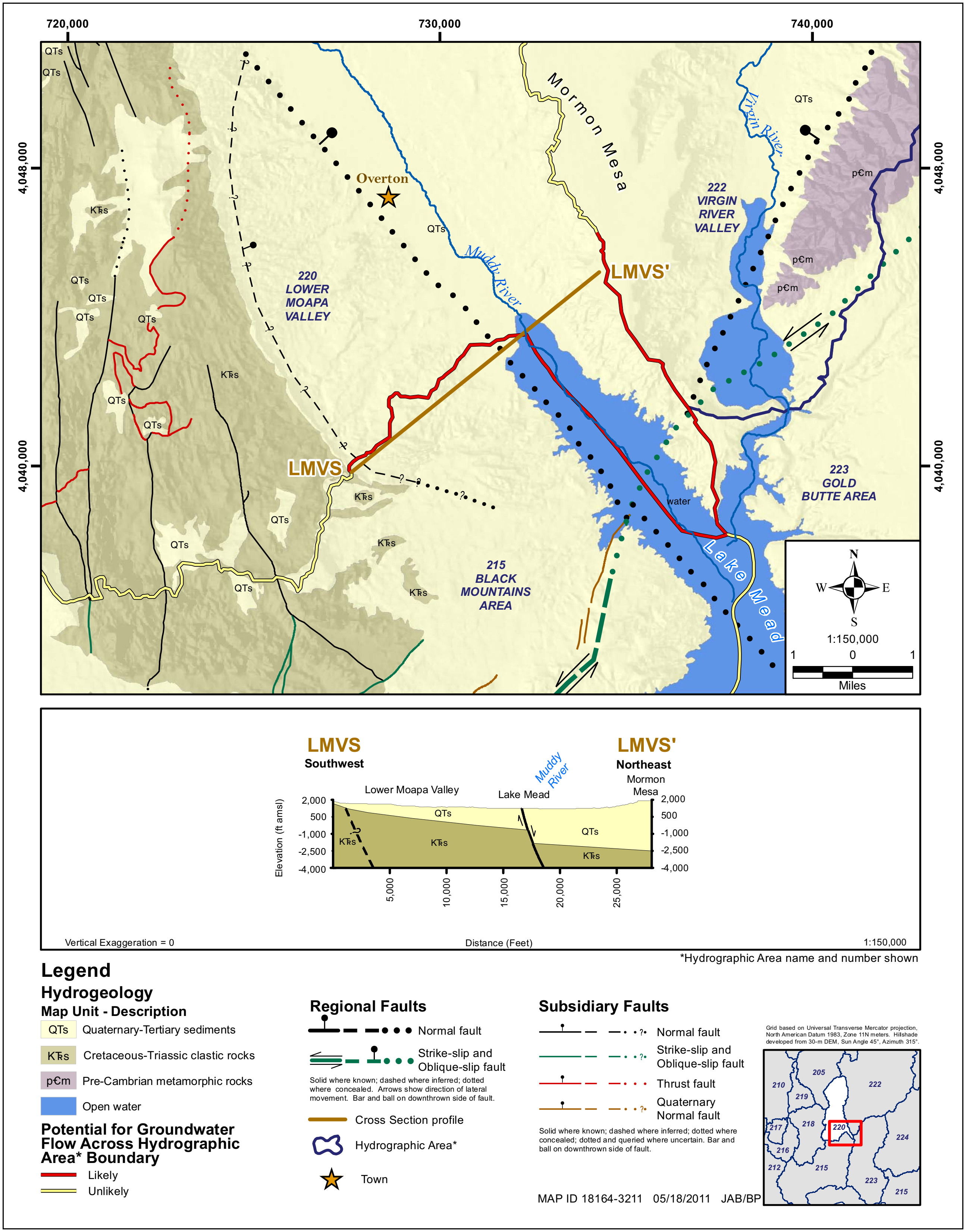
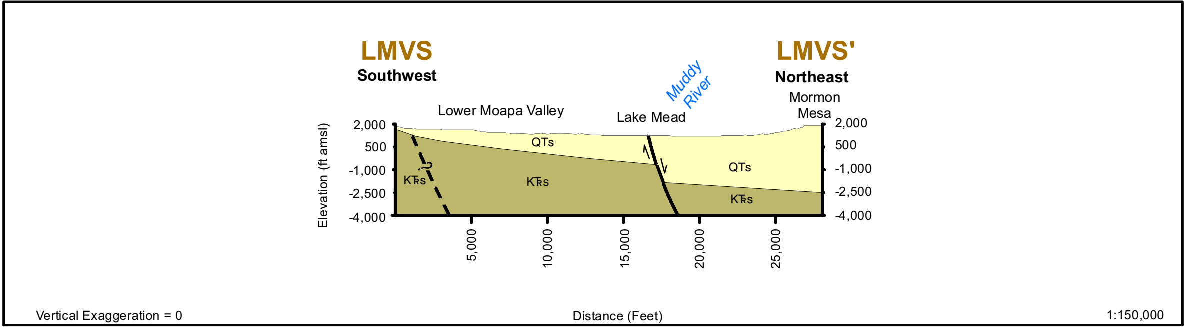
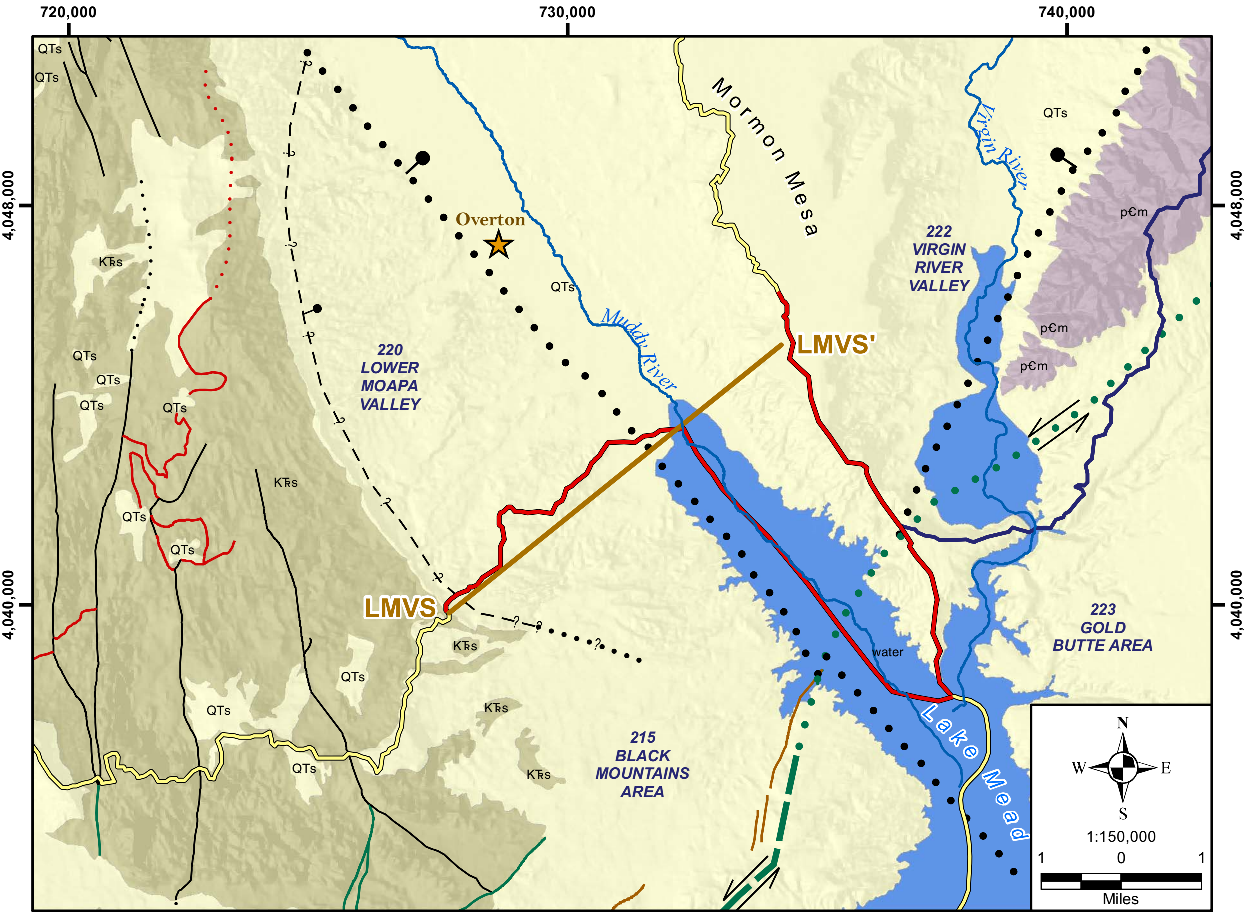


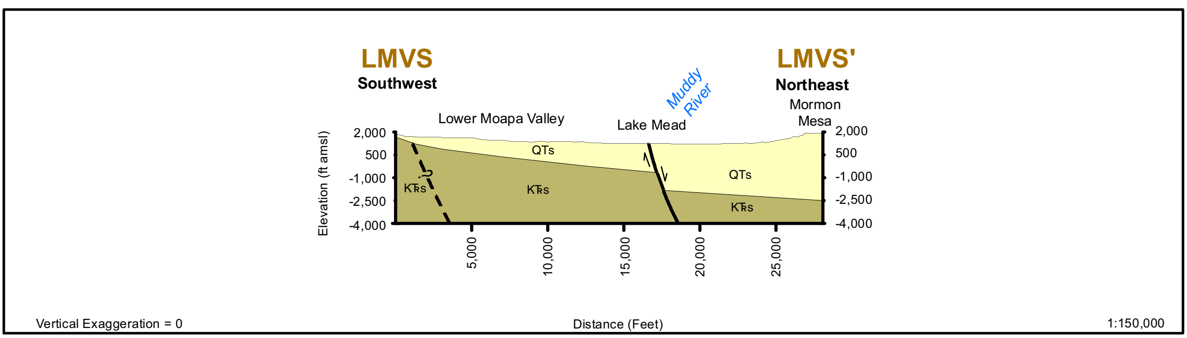
Figure 4-18
Hydrogeologic Map and Cross Section of the Lower Moapa Valley

SNWA Exhibit 58



*Hydrographic Area name and number shown





*Hydrographic Area name and number shown

Legend

Hydrogeology

Map Unit - Description

- QTs Quaternary-Tertiary sediments
- KTRs Cretaceous-Triassic clastic rocks
- pЄm Pre-Cambrian metamorphic rocks
- Open water

Potential for Groundwater Flow Across Hydrographic Area* Boundary

- Likely
- Unlikely

Regional Faults

- Normal fault
- Strike-slip and Oblique-slip fault

Solid where known; dashed where inferred; dotted where concealed. Arrows show direction of lateral movement. Bar and ball on downthrown side of fault.

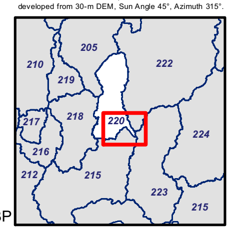
- Cross Section profile
- Hydrographic Area*
- Town

Subsidiary Faults

- Normal fault
- Strike-slip and Oblique-slip fault
- Thrust fault
- Quaternary Normal fault

Solid where known; dashed where inferred; dotted where concealed; dotted and queried where uncertain. Bar and ball on downthrown side of fault.

Grid based on Universal Transverse Mercator projection, North American Datum 1983, Zone 11N meters. Hillshade developed from 30-m DEM, Sun Angle 45°, Azimuth 315°.



MAP ID 18164-3211 05/18/2011 JAB/BP

Figure 4-18
Hydrogeologic Map and Cross Section of the Lower Moapa Valley

SNWA Exhibit 58

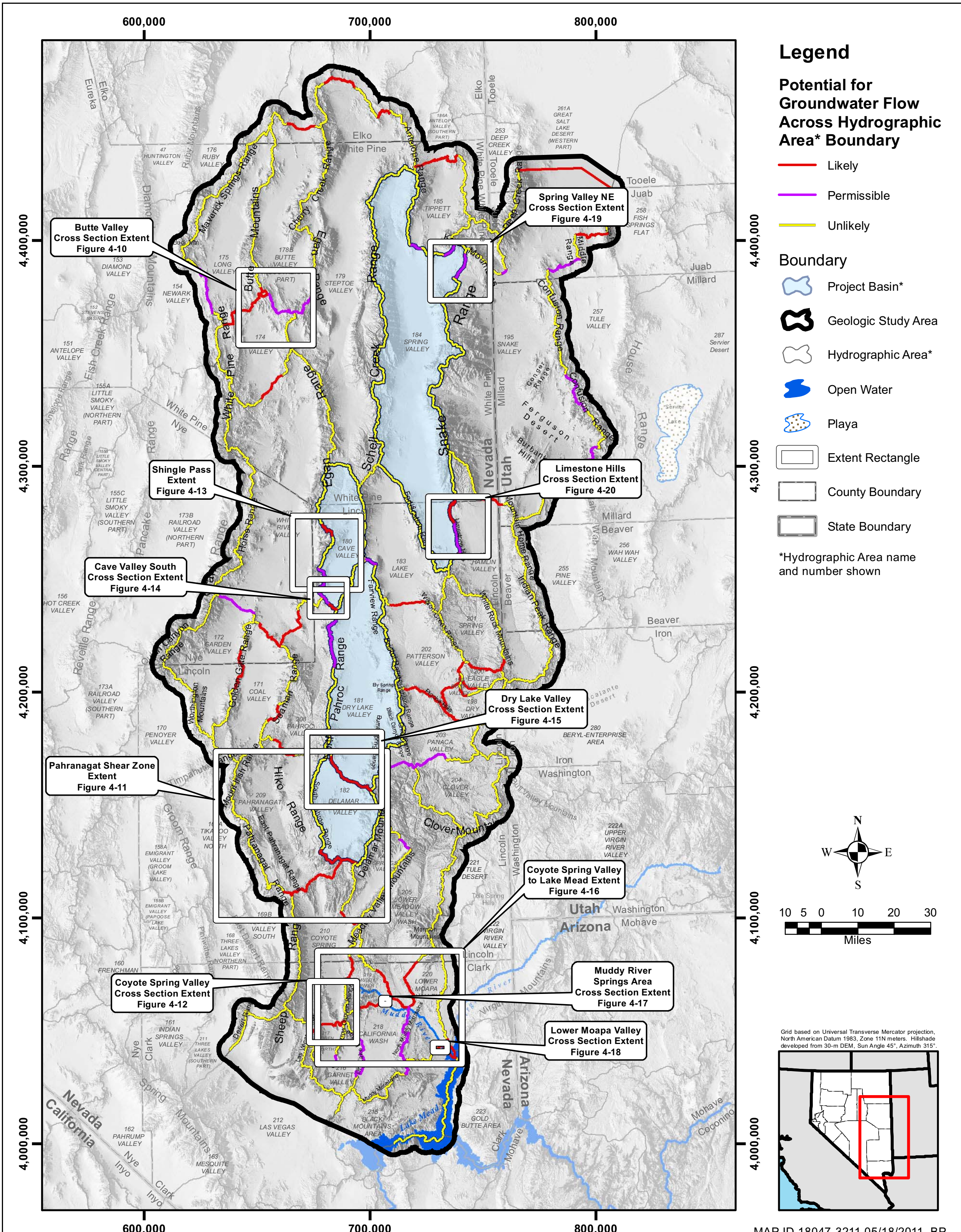


Figure 4-9

Potential for Interbasin Groundwater Flow within the Geologic Study Area

SNWA Exhibit 58

Volume 3

Physical Settings of Selected Springs in Clark, Lincoln, and White Pine Counties Groundwater Development Project

January 2008

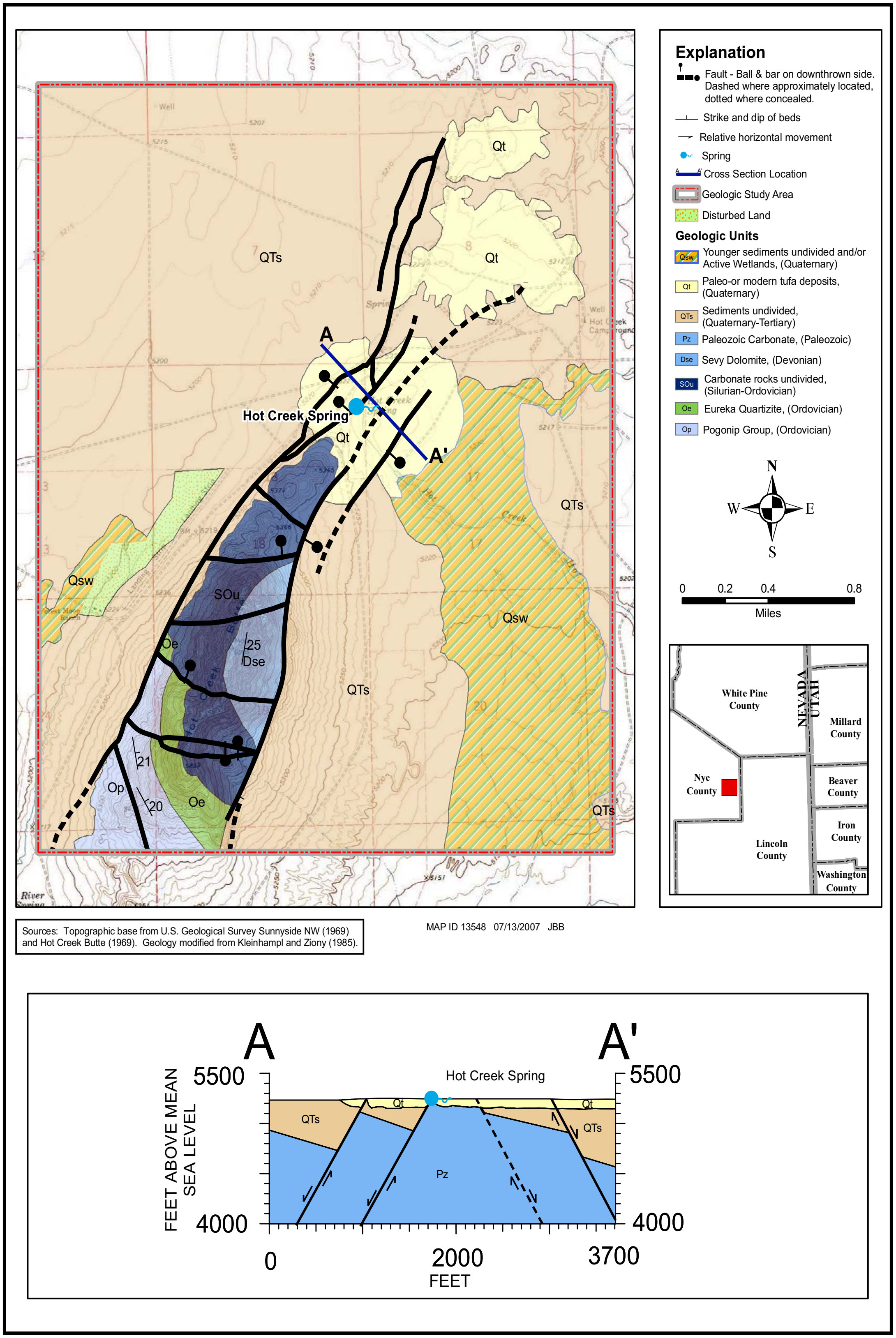
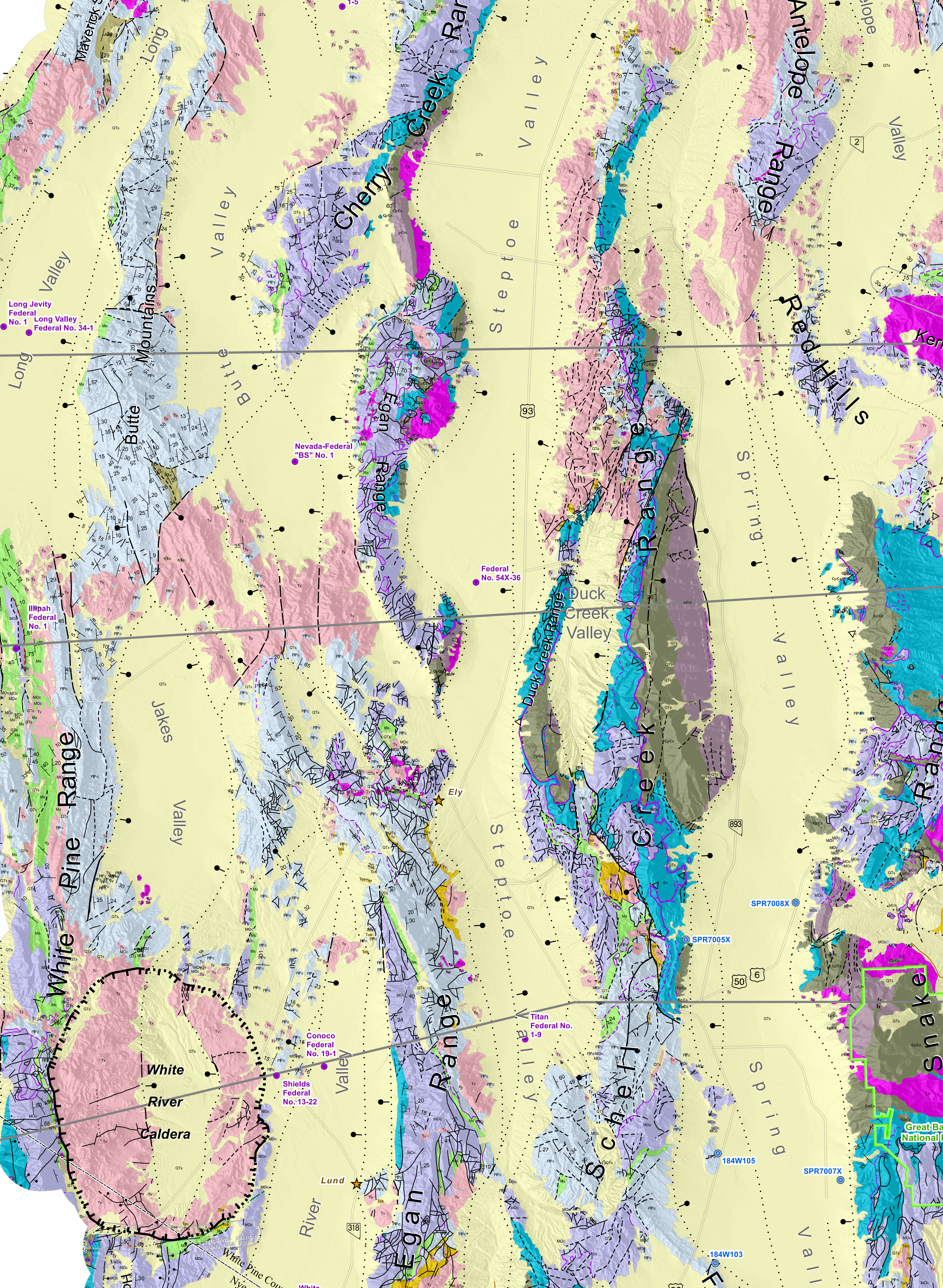
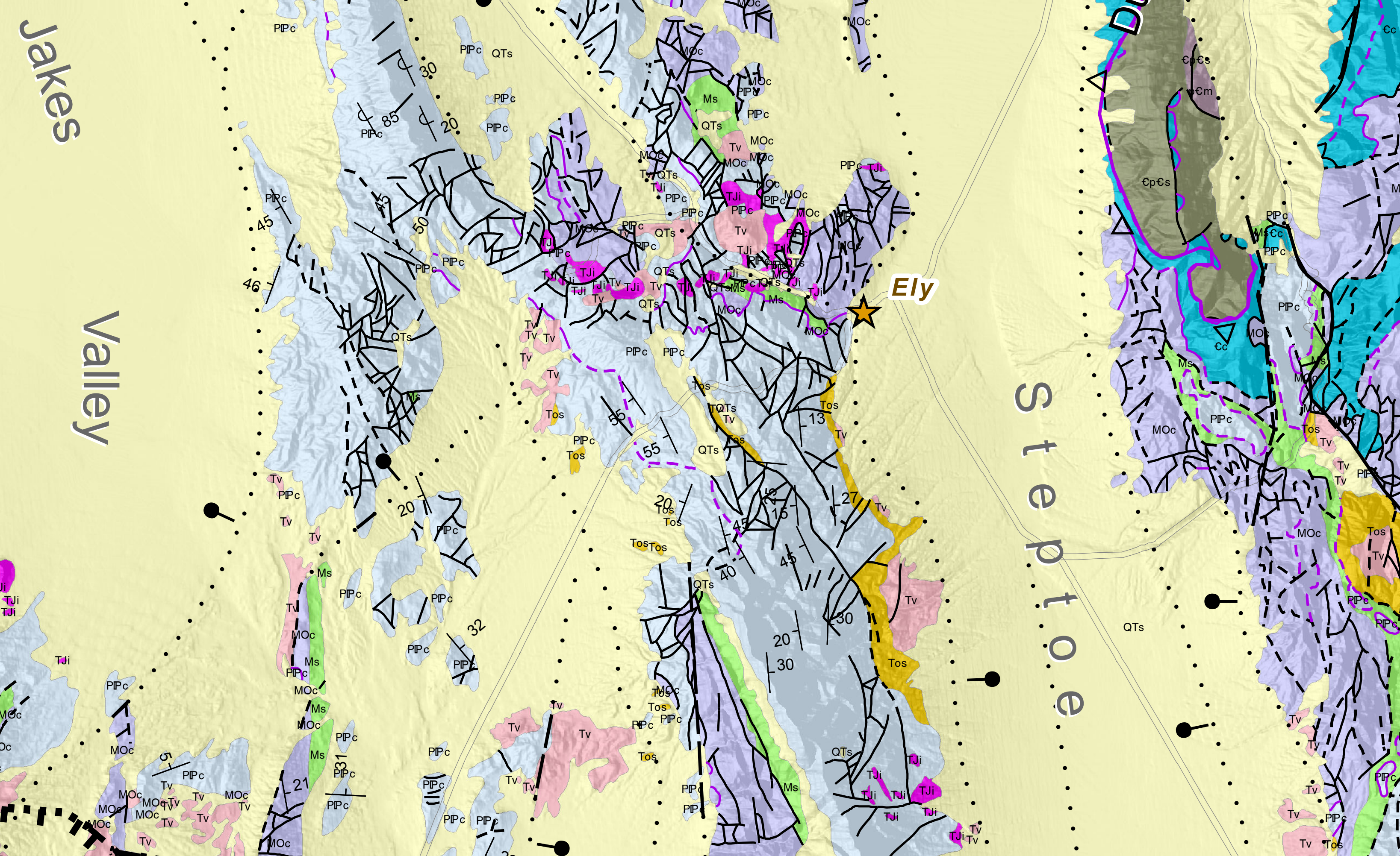


Figure 3-61
Geologic Map and Cross Section of Hot Creek Spring, Nye County, Nevada

SNWA Exhibit 70



Cherry Creek Range
Antelope Range
Steptoe Valley
Long Valley
Butte Valley
Butte Mountains
Red Hills
Egan Range
Duck Creek Range
Duck Creek Valley
Spring Valley
Schell Creek Range
Snake Range
Jakes Valley
White Pine Range
White River Valley
White River Caldera
Long Jevity Federal No. 1
Long Valley Federal No. 34-1
Nevada-Federal "BS" No. 1
Federal No. 54X-36
Illipah Federal No. 1
Titan Federal No. 1-9
Conoco Federal No. 19-1
Shields Federal No. 13-22
SPR7008X
SPR7005X
SPR7007X
184W105
184W103
Ely
Lund
Great Basin National Park
93
893
50
6
318
2


Jakes
Valley
Ely
Steptoe
QTs
Tv
Tos
TJi
PPc
MOc
Ms
Ms€c
€c
€p€s
€m

File M-1-D

OTH KEN

2

COPY

GROUND-WATER CONDITIONS IN THE VICINITY OF THE DEEP RUTH MINE AT RUTH, NEVADA

Prepared for

Kennecott Copper Corporation

Nov. 1959

Leggette, Brashears & Graham
Consulting Ground-Water Geologists
551 Fifth Avenue
New York

BHP 1032

posed mine workings.

A field inspection was made during January 1959 to investigate surface conditions and to observe ground-water conditions in the Deep Ruth Mine. An inspection was made of the various open pits in the area and the underground workings of the Deep Ruth Mine. In addition to the field inspection, a study was also made of the ground-water information in the files of the Nevada Mines Division at Ruth and in U. S. Geological Survey Professional Paper 96 (The Geology and Ore Deposits of the Ely, Nevada, by Arthur C. Spencer). The ground-water problem was discussed with J. C. Kinnear, Jr., R. C. Nispel, L. A. Green, H. L. Bauer, Jr., and other mining officials. Following the field inspection, the problem was discussed with S. D. Michaelson and C. B. Michaelson at the Kennecott Copper Corporation offices in Salt Lake City.

The ore body at the Deep Ruth Mine consists of weathered monzonite poryphry. It is surrounded by beds of shale and limestone. The monzonite and the beds of shale are relatively impermeable and yield very little ground water. The limestones, however, contain many fractures, faults and solution openings that contain large quantities of ground water in storage. Some of the fracture systems include openings that are closely interconnected and can readily transmit large quantities of ground water.

The limestones that produce water in the Deep Ruth Mine crop out extensively at the land surface, where they are readily recharged whenever moderately heavy precipitation occurs. Ruth, Nevada is located in a semi-arid region where the yearly

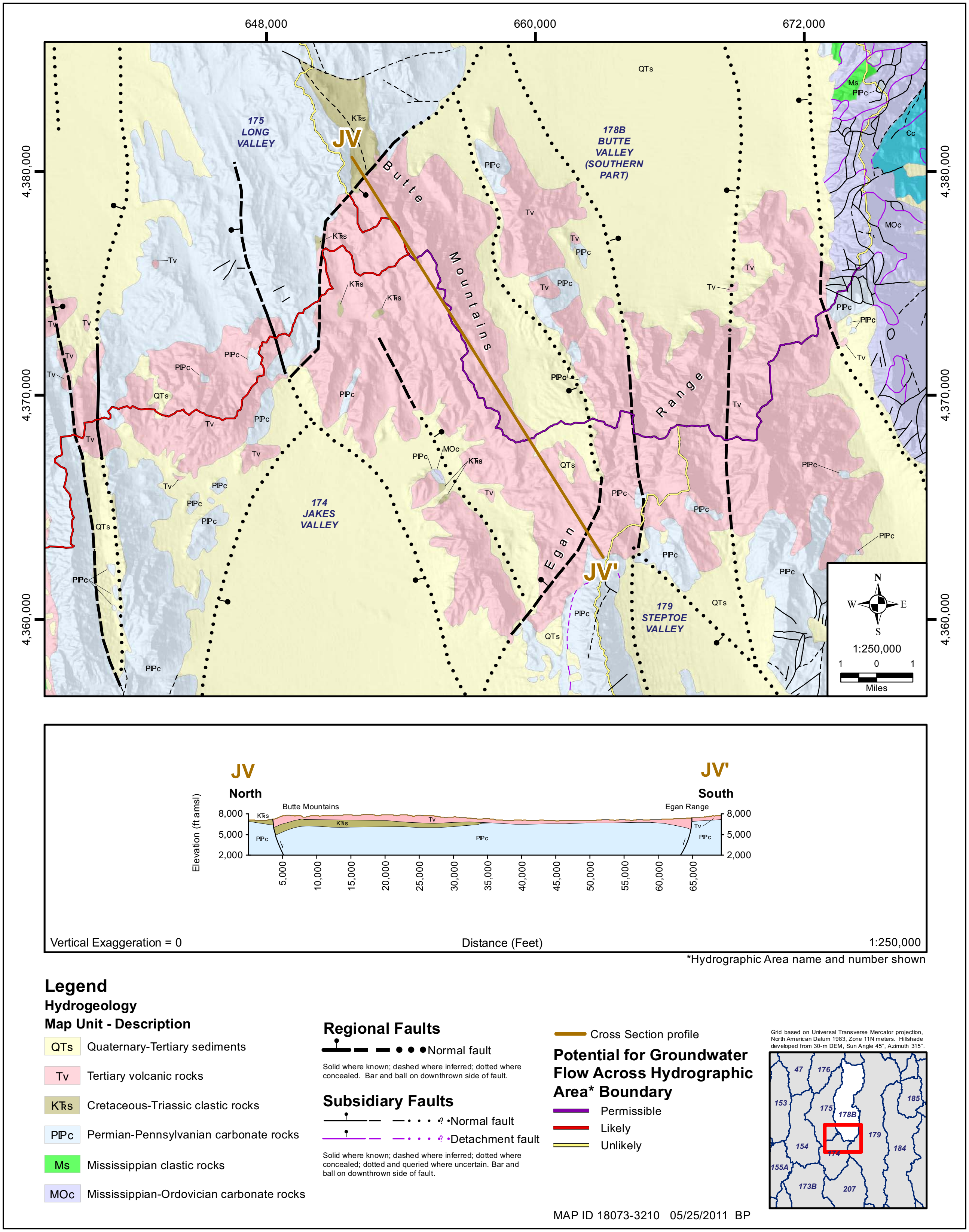
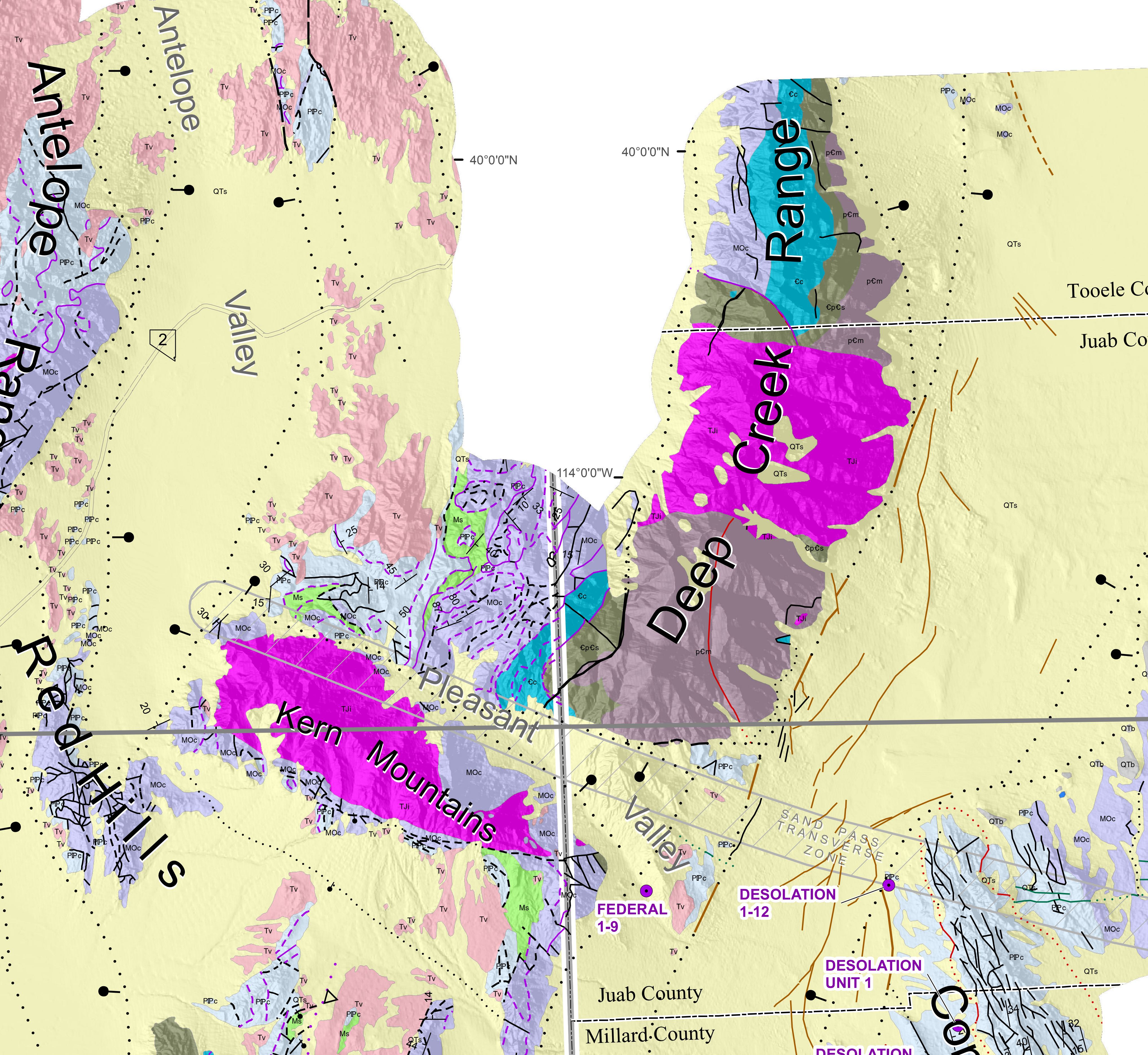


Figure 4-10

Hydrogeologic Map and Cross Section of Area between Butte Valley and Jakes Valley

SNWA Exhibit 58


Antelope
Antelope Valley
Red Hills
Kern Mountains
Pleasant Valley
Deep Creek Range
SAND PASS TRANSVERSE ZONE
40°0'0"N
40°0'0"N
114°0'0"W
Tooele Co
Juab Co
Juab County
Millard County
FEDERAL 1-9
DESOLATION 1-12
DESOLATION UNIT 1
2
QTs
Tv
PIPc
MOc
Ms
TJi
€c
€p€s
p€m
QTb