THE USE OF ISOTOPES IN DETERMINING ORIGIN AND FLOW PATHS OF GROUND WATER IN THE KELLY CREEK BASIN, NORTH-CENTRAL NEVADA

By

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THE USE OF ISOTOPES IN DETERMINING
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NOMENCLATURE

H	Hydrogen
D	Deuterium
T	Tritium
O	Oxygen
Pb	Lead
Sr	Strontium
U	Uranium
Th	Thorium
Rb	Rubidium
Ca	Calcium
He	Helium
K	Potassium
δ	delta
‰	per mil (parts per thousand)
gpd	gallons per day

CHAPTER I

INTRODUCTION

General Overview

The Kelly Creek drainage basin covers approximately 300 square miles in north-central Nevada (Figure 1). Kelly Creek and its tributaries drain the entire basin, eventually joining the Humboldt River in the vicinity of Golconda. The area, located in the Basin and Range physiographic province, is bounded by the Osgood Mountains to the west and the Snowstorm Mountains to the east. A gentle divide separates the valley from Chimney Reservoir to the north.

The study area constitutes 230 square miles in northern Kelly Creek Basin, and is located in eastern Humboldt County along the boundary with Elko County (Figure 1). Much of the study area, in and along the Osgood Mountains, is being actively mined for gold. The remainder of the valley is sparsely populated. Water-table data and water samples in the basin were obtained from mining company wells and drill holes, ranch wells, springs, and streams.

Objectives

The objectives of this study are to 1) construct a flow net of northern Kelly Creek Basin based on water-level measurements taken throughout the valley, 2) ascertain the age of the water travelling in the ground-water system by analyzing tritium isotopes, and 3) use stable

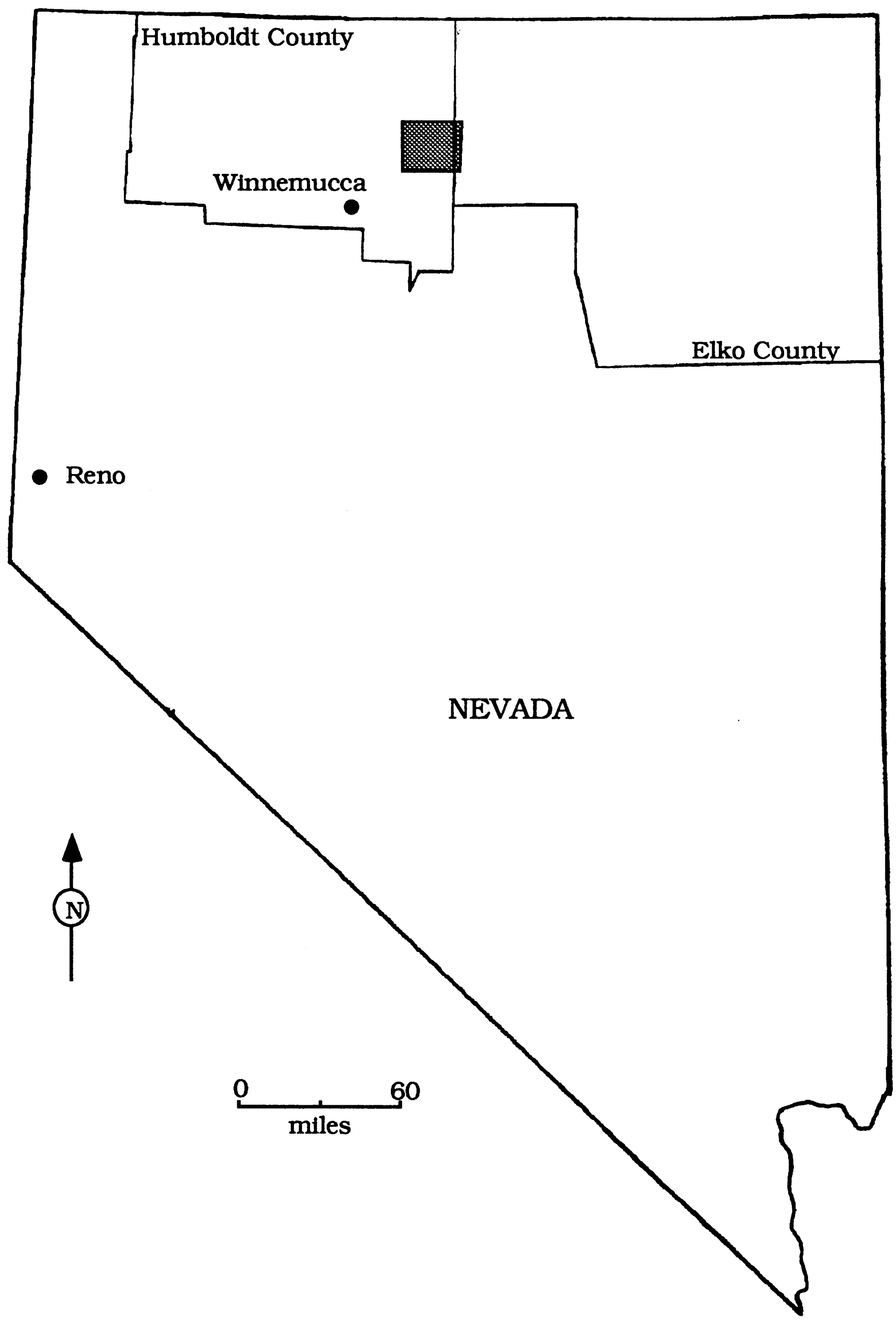


Figure 1. Location of Study Area.

(hydrogen and oxygen) and radiogenic (lead and strontium) isotopes to constrain the ground-water source(s).

Method of Investigation

The acquisition of the data in this investigation was aided by the Geologic Division and the Water Resources Division of the U. S. Geological Survey (USGS), Santa Fe Pacific Mining, Inc., Gold Field's Mining, FirstMiss Gold, Pinson Mining, and local ranchers. All funding was provided by the USGS, Branch of Geochemistry in Denver, Colorado.

Well logs, made available by the Water Resources Division (WRD) in Carson City, Nevada, were used to obtain preliminary ground-water information about Kelly Creek Basin. Although these logs do not account for annual and seasonal fluctuations, they do provide a generalized view of the ground-water system.

Water-table data and water samples were collected by the author during three different visits to the study area. The first visit, in June 1990, was devoted to reconnaissance of the area and measurement of depths to the water table. In February 1991, samples from wells, drill holes, and precipitation were taken for isotope analyses. In June of the same year, a final visit allowed for the collection of spring and stream samples.

Other data regarding hydrogeologic conditions existing in the valley were obtained by word of mouth from local ranchers and from consulting reports performed for mining companies. These data provided insight into aquifer characteristics existing within Kelly Creek Basin.

Previous Investigations

Geological Investigations

Most investigations of the Kelly Creek Basin region discuss the sediment-hosted gold deposits of the Osgood Mountains. Hotz and Willden (1964) described the geology and mineral deposits of the Osgood Mountains quadrangle. They provided unit by unit descriptions, as well as discussions about the metamorphic and structural history of the area. Silberman and others (1974) related the emplacement of a granodiorite stock to mineralization using K-Ar dates. Kretschmer (1984) detailed the geology of the Pinson and Preble gold deposits, including their relationship to structural features.

More recent work involves the study of alluvium overlying the concealed deposits. Detra and others (1989) received a 460 ft. core of alluvium from Santa Fe Pacific Gold. They described the chemical and physical characteristics of the core based on samples taken every 20 ft. Madden-McGuire and others (1990) described the same core but related the alluvium geochemistry to possible source regions. It appears, based on pebble and cobble composition, that the most likely source for valley-fill overlying the Rabbit Creek deposit of Santa Fe Pacific Mining, Inc., is the northern Osgood Mountains and the Dry Hills.

Ground Water Investigations

Aside from private consulting work, ground-water studies in Kelly Creek Basin are rare. The U.S. Geological Survey (D. Grimes, oral comm., 1990) is conducting an ongoing geochemical study on the use of ground water chemistry as a tool to locate gold mineralization. This study involves the measurement of water-level elevations and interval sampling down the water column of wells and drill holes. The goal is to determine if chemical variations in the water column can be used to constrain horizons favorable for gold mineralization.

Isotope Investigations

Jacobson and others (1983) used the stable isotopes of hydrogen and oxygen to examine the hydrology of Dixie Valley, a basin approximately 100 miles south-southwest of Kelly Creek Basin. They collected more than 100 samples of precipitation, hot and cold springs, streams, and ground water. From the precipitation samples they developed a local meteoric water line. By comparing the isotopic signatures of the precipitation with that of hot spring water in the valley, they were able to conclude that all ground waters could be isotopically derived from infiltrated precipitation. They also made use of tritium, the radiogenic isotope of hydrogen, in an attempt to date water in Dixie Valley; this resulted in only limited success. Pearson and Truesdell (1978) however, were able to constrain water ages for many of the hot springs and geysers in Yellowstone National Park using tritium.

Aside from tritium, the use of radiogenic isotopes in ground-water studies is uncommon. Fisher and Stueber (1976) found good correlations between strontium signatures of stream water and the strontium signatures of the rocks with which the stream was in contact. Andreyev and others (1967) did a comparable study of lead isotopes in waters throughout the Commonwealth of Independent States (formerly the U.S.S.R.). This large scale study concluded that the lead isotopic signature of the waters are a direct reflection of the lead isotopic signature of the rocks with which they are in contact. The only uses of strontium and lead isotopes in the vicinity of the Kelly Creek Basin were analyses performed on igneous intrusives and volcanic rocks in an attempt to unravel the tectonic history of the northern Great Basin (Farmer and DePaolo, 1983; Hart, 1985; Hart and Carlson, 1985); these serve as good reference data against which the strontium and lead isotopic compositions of ground waters collected in this study can be compared.

CHAPTER II

REGIONAL CHARACTERISTICS

Geography

Kelly Creek Basin encompasses an area of approximately 300 square miles in eastern Humboldt County and a small portion of western Elko County in north-central Nevada. Kelly Creek is the primary drainage in the intermontane basin that is bounded by the Osgood Mountains, the Dry Hills, and the Snowstorm Mountains (Figure 2). Adam Peak, in the Osgood Mountains, and the valley floor represent the highest and lowest points in the study area at 8,678 ft. and 4,593 ft., respectively.

The Osgood and Snowstorm Mountains rise abruptly from the valley-fill alluvium in typical basin and range fashion with vertical reliefs reaching 4,000 ft. (Figure 3). Both mountain ranges trend primarily N-S to NE-SW with several peaks exceeding 6,500 ft. The Dry Hills, a topographical-low northern extension of the Osgood Mountains, appear as rolling hills with a maximum elevation of 6,056 ft. The Snowstorm Mountains, which are the eastern border of the valley, tend to be more plateau-like in appearance than the Osgood Mountains, a function of local geology.

Streams in the region are commonly spring fed and flow intermittently through the year. They also tend to infiltrate and/or evaporate fairly rapidly once reaching the valley, particularly in summer months. Kelly Creek, Osgood Creek, Jake Creek, Summer Camp Creek, and

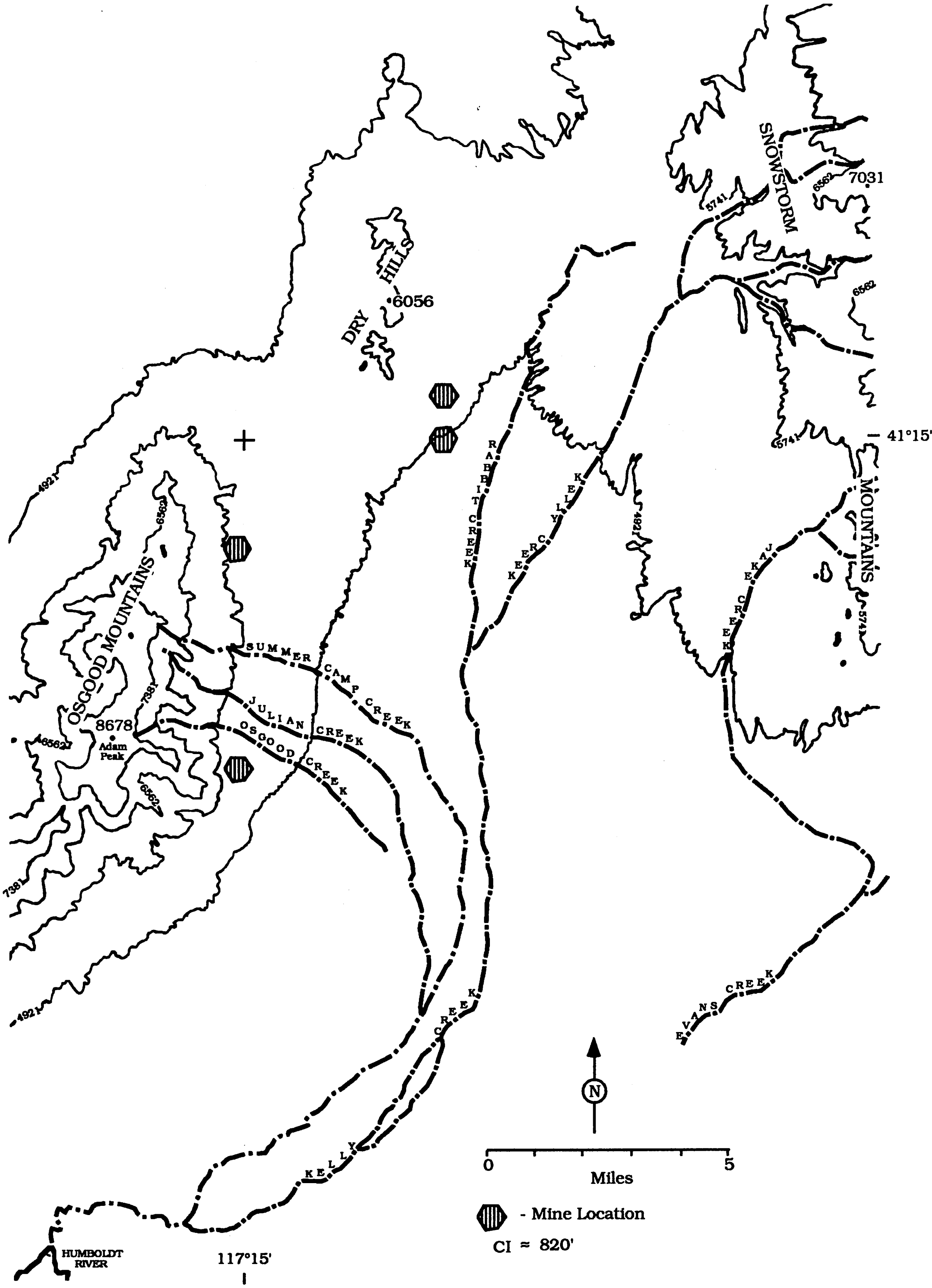


Figure 2. Topographic map of the Kelly Creek Basin

A.

B.

Figure 3. Photographs of ranges bordering the Kelly Creek Basin. A.) View looking west at the Osgood Mountains. B.) View of the Snowstorm Mountains.

Julian Creek represent the largest drainages in the basin and were the only ones observed to contain flowing water down-slope from the mountain fronts. The largest of these, Kelly Creek, has a width of 7-10 ft. at its most down gradient location in the study area.

Springs are abundant throughout the basin and are generally signified by the presence of green grasses, a spring house, or cattle watering tubs (Figure 4). In many instances however, flow is so minor that ground moisture is the only visible indication of a spring location. Springs are most abundant above 5,740 ft., and commonly originate at the headwaters of streams. Unlike other basins in Nevada where hot springs are not only common, but represent a viable geothermal resource, Kelly Creek Basin contains only those at Hot Springs Ranch in the southern portion of the valley, which are often not flowing.

There are four active gold mining operations located in, or adjacent to, the Osgood Mountains and Dry Hills on the west side of the valley. Numerous pits, tailings piles, prospect scars, mining equipment, and processing facilities symbolize past and present activity. Access roads throughout the area are almost entirely the result of mineral exploration.

Climate

The arid climate of Kelly Creek Basin is characterized by hot summers and cold winters. Maximum precipitation occurs in the winter and varies considerably with elevation. The nearest weather station, located 38 miles to the southwest in Winnemucca, registers an average annual precipitation of 3-9 inches (Pettyjohn and others, 1991). At the crest of mountain ranges, however, precipitation can reach 20 inches annually (Cohen and Everett, 1963). The mean annual temperature is approxi-

A.

B.

Figure 4. Photographs of springs in the Osgood Mountains. A.) View of green grasses indicative of a spring orifice. B.) Water flowing from a spring house.

mately 50° F (Fahrenheit), ranging from a daily maximum of greater than 105° F in the summer to less than -30° F in the winter. Diurnal temperature fluctuations in this region can be quite extreme, especially in the summer; variations of up to 40° F are not uncommon due to a lack of cloud cover combined with dry air.

Storm systems generally approach north-central Nevada from the west and result in minimal precipitation due to the rain shadow effect of the Sierra Nevada. Winds, however, can be quite gusty, typically reaching 40 miles per hour. They are usually westerly and tend to increase in the afternoons.

Soils

Soils in Kelly Creek Basin are given the broad classification of aridisols, based on moisture and temperature conditions of the region. They have developed predominantly on the valley-fill alluvium, but they also exist in the adjacent mountains where slopes permit. Varieties of loam make up the soil texture of this area. Slopes and closeness to stream drainages usually dictate what modifying term precedes loam. Steeper slopes generally result in a coarser modifier. The U. S. Department of Agriculture-Soil Conservation Service in Winnemucca supplied the soil information for eastern Humboldt County. Table I lists the dominant soil names individually, although associations of two or more of these are generally grouped together within map units.

Vegetation

Flora is typical of that found throughout the northern basin and range region. Sagebrush (Artemisia arbuscula and/or Artemisia

TABLE I

SOILS OF THE KELLY CREEK BASIN

Area	Soil Name(s)	Texture	Slope(%)
Jake Creek	Bliss	f. sandy loam	0-4
	Orovada	v.f. sandy loam	0-4
	Shabliss	f. sandy loam	0-4
	Golconda	silt loam	2-8
	Soughe	cobbly loam	4-30
	Vanwyper	v. cobbly loam	30-50
Evans Creek	Broyles	v.f. sandy loam	2-8
	Orovada	v.f. sandy loam	2-8
Osgood Mts.	Gowjai	silt loam	15-50
	Vanwyper	v. cobbly loam	15-50
	Sumine	v. cobbly loam	30-50
Dry Hills	Chiara	f. sandy/grav. loam	2-4
	Hunnton	v.f. sandy loam	8-15
	Boger	v.f. sandy loam	4-15
	Vanwyper	stony loam	15-50
	Havingdon	v. cobbly loam	15-50
	Puffer	v. cobbly loam	30-50
	Soughe	v. stony loam	30-50
	Flue	gravelly loam	2-8
	Snapp	v.f. sandy/cob. loam	2-15
Kelly Creek/ Rabbit Creek	Flue	v.f. sandy loam	2-4
	Golconda	silt loam	2-4
	Snapp	v.f. sandy loam	4-15
	Connel	f. sandy/grav. loam	0-2
	Clementine	silt loam	0-2
	Rose Creek	loam	0-2
	Kelk	v.f. sandy/silt loam	0-2
	Orovada	v.f. sandy loam	2-8
Lower Kelly Creek	Bubus	v.f. sandy loam	0-2
	Needle Peak	silt loam	0-2

TABLE I (Continued)

Area	Soil Name(s)	Texture	Slope(%)
Upper Kelly Creek	Chiara	f. sandy loam	2-4
	Hunnton	v.f. sandy loam	8-15
	Flue	silt loam	0-2
	Connel	f. sandy/grav. loam	0-2
	Ninemile	gravelly loam	4-50
	Tusk	gravelly loam	15-50
	Clementine	silt loam	0-2
	Paranat	silt loam	0-2
	Soughe	cobbly loam	4-30
	Vanwyper	v. cobbly loam	30-50

v.-very, v.f.-very fine, f.-fine

tridentata) covers the main valley and much of the surrounding mountains. Thurber needlegrass, bottlebrush squirreltail, and sandberg bluegrass are also common. In places where the water table is shallow (<10 ft.), green grasses dominate, particularly creeping wildrye and basin wildrye. Trees in the area are found in tributary valleys of the Osgood and Snowstorm Mountains, or nestled around ranches. Most of the canyon growth consists of aspen (Populus tremuloides) and willows. The canyon at the head of Osgood Creek also contains man-planted apple trees located down gradient from a series of springs. Cottonwoods (Populus deltoides and/or Populus fremontii) are found around most of the ranches in Kelly Creek Basin. They are planted for shade and windbreaks, and are well-suited for desert conditions. They can withstand dry alkaline soils, high winds, and extreme seasonal temperature fluctuations.

Population and Culture

Kelly Creek Basin has less than 30 residents, and not all of them inhabit the valley year round. Of these, a majority are made up of two families, the Christisons and the Hammonds. Both are ranchers and rely on cattle for their livelihood. Only one farm exists in the basin because irrigation is necessary and water well permits are difficult to acquire from the state. This farm produces alfalfa and covers an area of 1,400 acres.

Since gold was discovered in the Osgood Mountains in 1934, mining and exploration have dominated activity in the valley. Through the years, tungsten and gold have been produced at fluctuating rates based on market prices. Currently, four large gold operations are extracting and processing ore. They play a vital role in making Nevada one of the leading gold producing states in the country. Also, they provide hundreds of jobs and a boost to local economies.

CHAPTER III

GEOLOGY OF THE KELLY CREEK BASIN

General

North-central Nevada is located in the Basin and Range physiographic province and is characterized by N-S to NE-SW trending block-faulted mountain ranges. These are the result of Cenozoic tectonism that resulted in crustal extension throughout much of western North America. Extension is believed to have commenced about 17 million years ago and was accompanied by eruptions of basalt, or bimodal assemblages of basalt and rhyolite (Williams and Lipman, 1972 in Stewart, 1980). Present day topography is the result of the relative uplift or sinking of adjacent linear blocks along normal faults. The weathering of uplifted segments produced rapid alluviation over the downdropped segments. The amount of valley-fill varies considerably throughout the province, ranging from a few hundred feet to more than 10,000 ft. (Williams, 1983). In Kelly Creek Basin, maximum valley-fill is believed to exceed 1,500 ft. at the southern reaches of the study area.

Cenozoic extension was a late stage in the structural evolution of Nevada. Numerous periods of orogenic activity preceded extension resulting in a considerable amount of structural overprinting in the rocks of the Kelly Creek Basin. The orogenic events, as well as the major structural features associated with them, are listed in Table II.

Beginning in Late Devonian time, the Antler Orogeny caused a north-northeast trending welt to rise across present day Nevada. As compression continued, rocks became sharply deformed and the Roberts Mountain Thrust developed (Wallace, 1964). It led to the eastward movement of siliceous and volcanic rocks, in some cases over distances as much as 90 miles, over mixed sedimentary rocks and carbonates (Wallace, 1964). By Early Mississippian time the orogeny had ceased, and by Middle Pennsylvanian time sediments were again being deposited across the axis of the Antler orogenic belt (Wallace, 1964).

TABLE II

OROGENIC EVENTS THAT HAVE AFFECTED THE KELLY CREEK BASIN STUDY AREA

Name	Age	Feature(s)
Antler Orogeny	L. Devonian - E. Mississippian	Roberts Mountain Thrust
Sonoma Orogeny	L. Permian - E. Triassic	Golconda Thrust
Cenozoic Extension	Cenozoic	Normal Faulting and Volcanism

In Late Permian time another period of deformation, the Sonoma Orogeny, commenced, and compressional forces again produced folding and thrusting. Early Triassic time marked the end of the Sonoma Orogeny, but igneous activity continued throughout the Mesozoic. Many batholiths and stocks of granitic, monzonitic, and dioritic composition are believed to have been emplaced during Late Jurassic and Cretaceous time. A generalized view of the basinal geology is shown in Figure 5.

Osgood Mountains

The Osgood Mountains consist of a structurally complex package of predominantly Paleozoic rocks that have undergone several episodes of folding and faulting. The age and a brief description of the major units (Hotz and Willden, 1964) are listed in Table III.

The strikes of the main structural elements, including axes of folds, bedding of sedimentary rocks, and major thrusts, are all oriented N-S to NE-SW (Hotz and Willden, 1964). Steeply-dipping, mostly vertical, northwest-trending cross faults cut the rocks nearly perpendicular to the northeast structures (Hotz and Willden, 1964). Basin and range normal faults represent the youngest features in the area. The largest of these appears as a 100 ft. wide fault zone on the eastern flank of the range.

Snowstorm Mountains

The Snowstorm Mountains make up the eastern border of northern Kelly Creek Basin. They expose middle Miocene mafic to felsic volcanic flows and pyroclastic rocks covered by rhyolite flows, peralkaline ash-flow tuffs, crystal rich rhyodacite domes, and upper Miocene and Pliocene basalt flows, with Paleozoic sedimentary rocks exposed in erosional windows (Wallace, 1989 in Madden-McGuire and others, 1990).

Along the west side of the range, most rock outcrops examined by the author were basaltic flows. They tended to be vesicular and locally amygdaloidal. Some vesicles reach 2 inches in diameter. In the upper

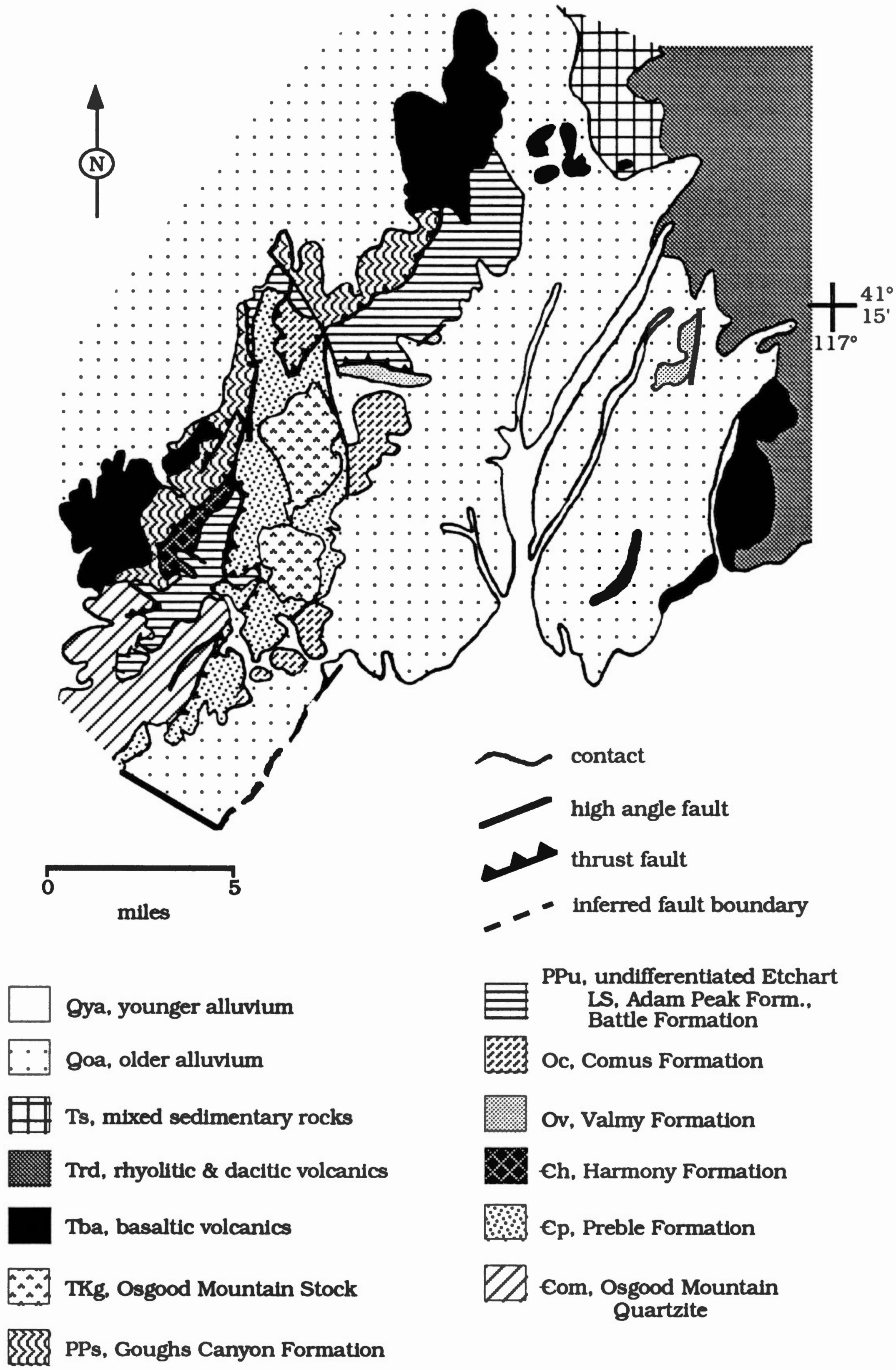


Figure 5. Geology of the Kelly Creek Basin (Modified from Willden, 1963).

TABLE III

UNIT DESCIPTIONS OF THE OSGOOD MOUNTAINS STRATIGRAPHY

Age	Formation Name	Description
Quaternary	Surficial deposits	Includes young and old alluvium, fan gravels, and talus
Late Cretaceous	Osgood Mountain Stock	Granodiorite, locally altered and cut by aplite dikes and small dikes and veinlets of quartz-feldspar pegmatite
Early Permian-Middle Pennsylvanian	Etchart Limestone	Limestone and sandy limestone, with some interbedded dolomite, minor amounts of calcareous shale, and lenticular beds of conglomerate
	Adam Peak Formation	Shale, siltstone, dolomitic sandstone, and chert with some limestone and dolomite
	Battle Formation	Terrestrial conglomerate which underlies and interfingers with the Etchart Limestone
Early to Late Mississippian	Goughs Canyon Formation	Altered volcanics of medium to basic composition, coarse grained fossiliferous limestone, and minor amounts of calcareous shale, siliceous shale, and chert

TABLE III (Continued)

Age	Formation Name	Description
Ordovician	Comus Formation	Alternating sequence of dolomite, limestone, and shale with subordinate amounts of chert, siltstone, and tuffaceous (?) material
	Valmy Formation	Chert and siliceous shale
Cambrian	Harmony Formation	Feldspathic sandstone and shale with some limestone and minor chert
	Preble Formation	Predominantly shale with a few quartzite beds in its lower part, and interbedded limestone and shale in the middle and upper parts
	Osgood Mountain Quartzite	Relatively pure cross bedded quartzite with a few thin shaley partings

reaches of Kelly Creek, rhyolite and ash-flow tuffs are present in the vicinity of some old prospects. The area is locally intensely iron stained, but no mineralization is visible. The Knolls are three hills trending N-S along the western margin of the Snowstorm Mountains. Chert and limestone crop out in a small zone within these hills marking the only viewed sedimentary exposure on the east side of the basin.

Valley-Fill Sediments

The valley-fill sediments represent the weathering products of the Osgood and Snowstorm Mountains, as well as the Dry Hills. Alluvium derived from the Osgood Mountains and Dry Hills is composed of fragments of chert, shale, siltstone, sandstone, conglomerate, limestone, and granodiorite. Fragments derived from the Snowstorm Mountains however, are dominantly Tertiary volcanics.

The lithologic differences usually lead to Osgood weathering products containing a higher percentage of silt and clay than the Snowstorm weathering products. The compositional and textural changes allow for distinctions to be made on the predominant source areas for alluvium at different locations within the basin. There is some degree of interfingering based on the distance from a respective mountain range.

Vertical textural changes can be significant in the alluvium. Paleoplaya or paleolacustrine deposits form clay lenses, while fan deposits form conglomeratic zones. Variability in the degree of lithification also exists. These factors have a major effect on the hydrology of the basin.

A detailed description of the alluvium from a drill hole in the vicinity of the Rabbit Creek gold deposit, southeast of the Dry Hills, is discussed in Madden-McGuire and others (1990). They propose, based on changes in clast type, mineralogical changes, and sorting, that the source area for the alluvium from this drill hole is to the north and west. The alluvium is generally composed of very poorly sorted, polymictic gravel to conglomerate that is locally highly calichefied. Vertical compositional changes indicate that source area alluvial contributions from bordering ranges as a result of weathering has not been constant during the life of the basin.

CHAPTER IV

HYDROGEOLOGY OF THE KELLY CREEK BASIN

Hydrologic System

The hydrogeologic characteristics of Kelly Creek Basin are typical of those found in much of the Basin and Range Province. It is an intermontane basin with a considerable amount of sediment accumulation in the valley that is bordered and underlain by bedrock (Figure 6). The ground-water table somewhat mimics topography, with depths to water being quite extreme in the mountains (>500 ft.), while remaining relatively shallow near Kelly Creek (<50 ft.).

The valley-fill is considered a semi-confined aquifer. Localized clay lenses create confined conditions, but long-term pumping results in a conversion to a water-table situation in the upper part of the alluvial fill. Structure of the bedrock plays a major role in the ground-water conditions in the mountains and beneath the valley-fill. Faults, fractures, and joints allow for hydrologic communication between bedrock and alluvium as ground water travels from recharge areas to discharge areas.

Three broad categories of flow systems have been recognized in this structurally controlled region: 1) local flow systems essentially confined to hydrographically closed basins, 2) regional flow systems where important interbasin ground water flow occurs, and 3) integrated flow systems where ground water of associated basins is linked by surface transfer between basins (Mifflin and Harrill, 1981).

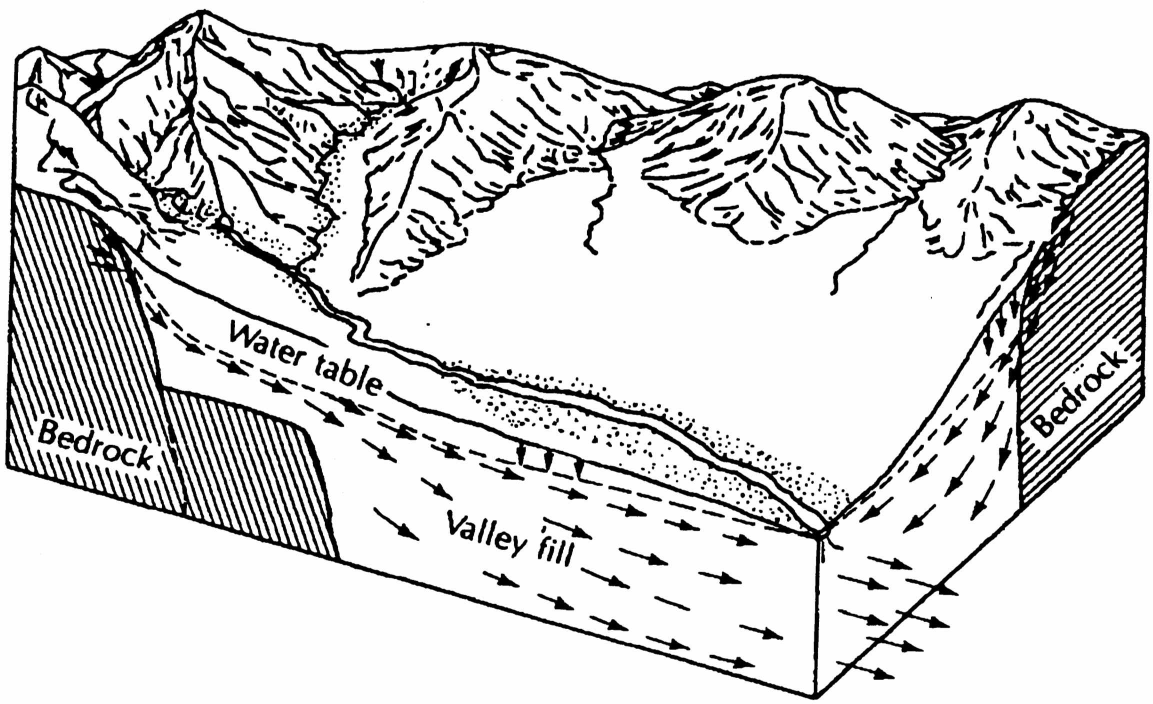


Figure 6. Generalized block diagram of a basin and range hydrologic system (Modified from Eakin and others, 1976 in Fetter, 1988).

Nevada is divided into 39 hydrogeologic systems, and each contains a different number of hydrographic areas. The Humboldt System, of which the Kelly Creek Area is a part, contains 34 hydrographic areas (Figure 7). The study area encompasses approximately 230 square miles of the 16,800 square miles in the Humboldt Flow System. This represents less than 2% of the system, and the calculated annual recharge is less than 7,000 acre-ft/year. Virtually no water leaves the valley as streamflow, except during unusually high runoff periods in the spring. Streams are losing once they reach the valley floor (Figure 8), and give up considerable amounts of water to evaporation and transpiration. Although structural controls complicate the ground-water system in the mountains, general flow for basinal water is towards Kelly Creek and ultimately southward to the Humboldt River. Regional discharge is to the Humboldt Sink, approximately 150 miles to the southwest, which occurs at an altitude of 3,890 ft.

Surface Water

Surface water in Kelly Creek Basin flows intermittently through the year. Most of the drainages are fed by springs and snowmelt at elevations exceeding 5,250 ft. The water in these drainages infiltrates and/or evapotranspirates rapidly upon reaching the alluvial fans and the valley proper. Almost all of the streams in the basin are tributaries of Kelly Creek. It, in turn, flows into the major drainage of northern Nevada, the Humboldt River.

Kelly Creek and Jake Creek are the only streams that flowed during the three visits by the author to the study area. During a late June 1990 visit, they were the only drainages that contained flowing water at

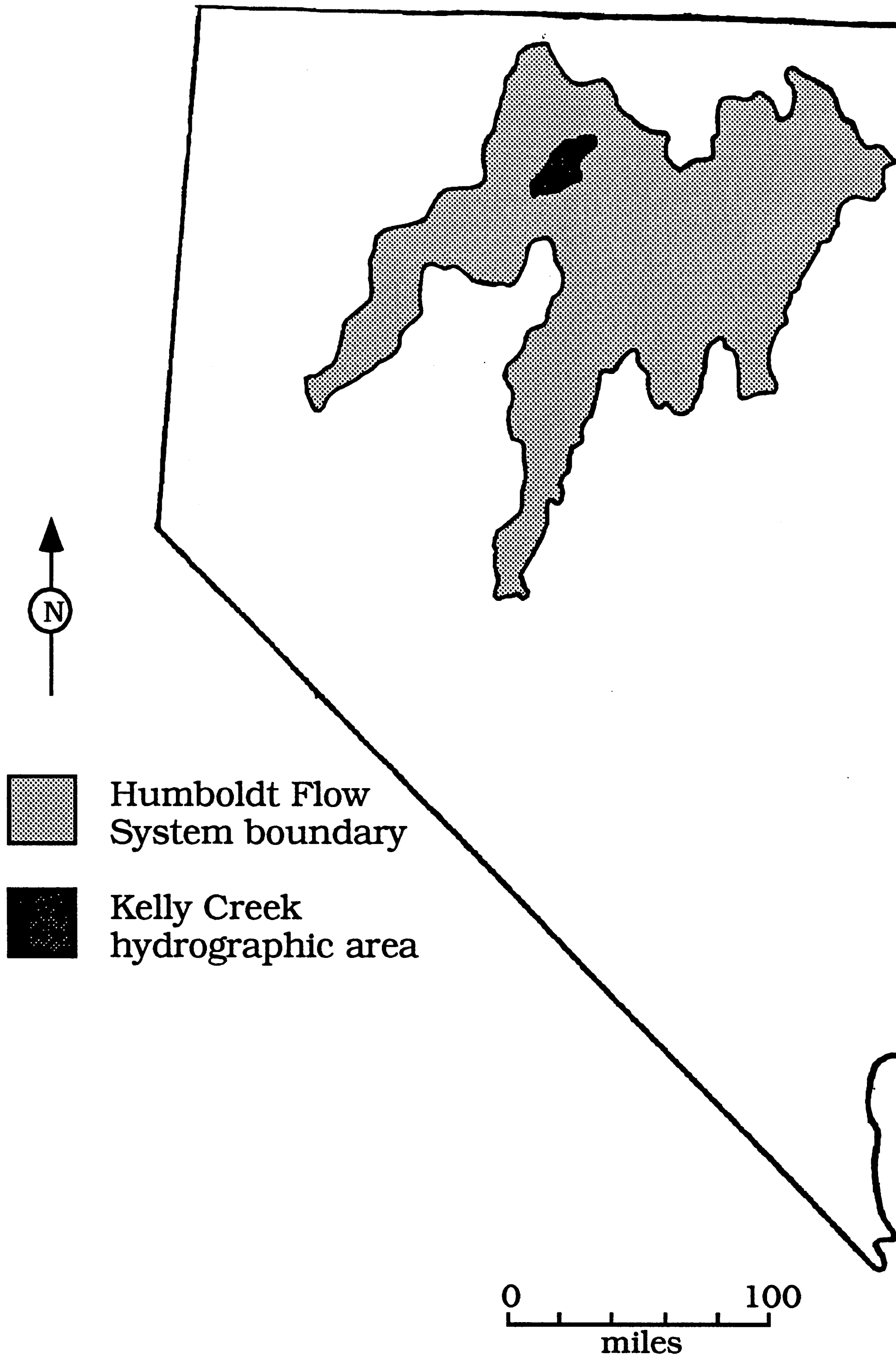
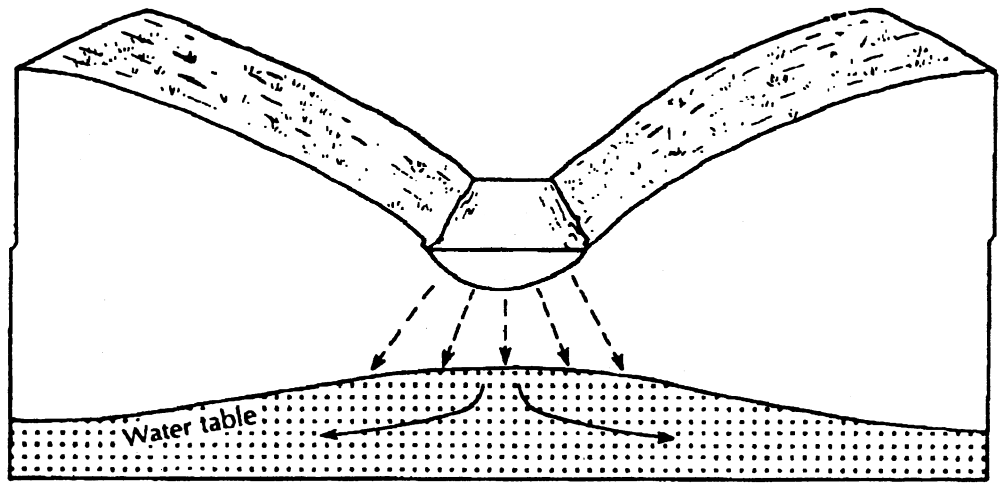
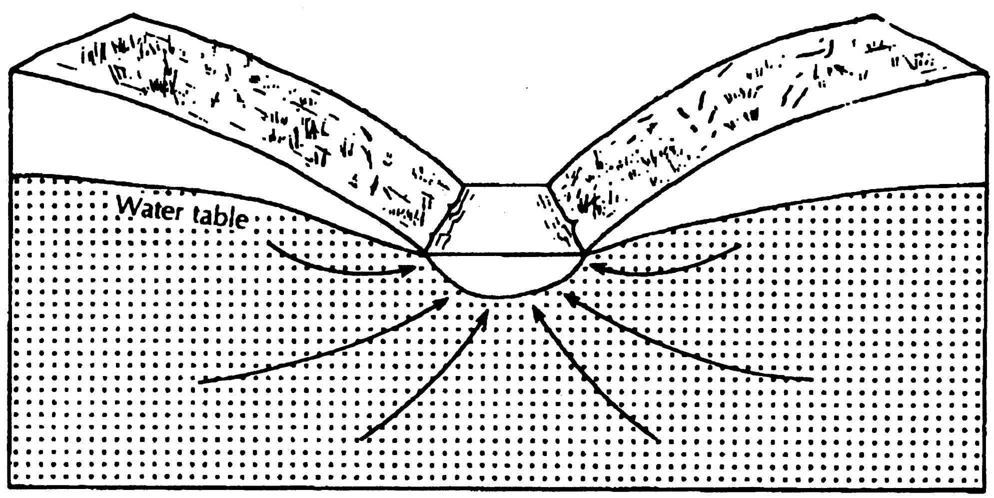


Figure 7. Location of the Humboldt Flow System and Kelly Creek hydrographic area (Modified from Harrill and others, 1988).



A.



B.

Figure 8. Cross-sections of losing and gaining streams. A.) Losing stream and B.) gaining stream (Modified from Fetter, 1988).

elevations below 5,000 ft. Both, however, infiltrated and/or evapotranspirated by the 4,600 ft. elevation level. In mid February 1991, conditions were similar to the previous visit except that the streams were dry below an altitude of 4,750 ft. The final visit in early June 1991 proved quite different. Kelly Creek flowed beyond the study area boundary, and three streams draining the Osgood Mountains, Julian Creek, Summer Camp Creek, and Osgood Creek, all contained water beyond the range front.

A majority of the surface water in the basin is derived from or becomes ground water. Infiltration of snowmelt at elevations above 6,000 ft. commonly travels along structurally controlled localized flow paths that discharge at springs. The volume of water supplied to surface drainages by springs has a large impact on the discharge of streams in this region. Drainages can be gaining (Figure 8) in their upper reaches within the mountains, but water quantities are generally not sufficient to sustain flow once reaching the valley floor. Surface runoff is believed to contribute to streams only in the spring, and amounts are highly variable.

Ground Water

Subsurface Characteristics

Structural and sedimentological conditions within the Kelly Creek Basin result in a hydrologic system that has extremely variable groundwater parameters. There is no "aquifer" in the basin, but most of the producing wells tap zones in the valley-fill. Some of the parameters used to evaluate hydrologic conditions are transmissivity, hydraulic conductivity, specific yield, storativity, and saturated thickness where:

Transmissivity (T): capacity of an aquifer to transmit water of a given kinematic viscosity (units-gpd/ft).

Hydraulic conductivity (K): describes the rate at which water can move through a permeable medium (units-gpd/ft^2).

Specific yield (Sy): ratio of the volume of water a rock or soil will yield by gravity drainage to the volume of the rock or soil.

Storativity (S): the volume of water an aquifer takes in or releases from storage per unit surface area of the aquifer per unit change in head.

Saturated thickness (m): pore space of an aquifer that is occupied by water.

where T=Km, and S=Sy for unconfined conditions.

Most of the hydrologic data for Kelly Creek Basin has been acquired from mining company consulting reports. The valley is considered a basin-fill alluvial aquifer with a transmissivity of 20,000-30,000 gpd/ft, a specific yield of 0.1 (assumes unconfined conditions), and a saturated thickness of 1,000 ft. Locally, these values vary considerably. Clay lenses reduce transmissivity values and create confined conditions. This causes storativity to change to about 0.0004. However, pumping converts storativity back to 0.1 and diminishes the artesian effects of the lenses. Saturated thickness undulates with the bedrock surface, but a general thickening occurs in a mid-basin direction. Hydraulic conductivity is between 20 and 30 gpd/ft^2, with alluvium ranging from cobble to clay. This indicates that features other than grain size are playing a role in the permeability of the basin-fill.

Hydrologic conditions within the Osgood and Snowstorm Mountains are directly related to the geologic complexity. The presence of wells is scarce due to the depths to water and a lack of homogeneity in the subsurface. Depending on the amount of fractures, hydraulic conductivity values vary from 10^{-7} to 10^{5} gpd/ft^{2}. The wide range in the values shows the significance of structural features in evaluating ground-water conditions. Surface expressions and spring locations indicate an abundance of faults and fractures throughout both ranges, making attempts to define hydrologic parameters a difficult task.

Water-Table Measurements

Ground-water elevations were measured primarily in mining company drill holes. The drill holes are concentrated in and just east of the Osgood Mountains, where auriferous bedrock exists. Therefore, the density of ground-water elevation data is considerably greater in this area than in other parts of the valley where only ranch wells could be sampled.

A 500 ft. battery operated probe was used to determine depth to water (Figure 9). For drill holes and mining wells, the surface elevation was commonly surveyed during drilling, allowing for water-level elevations to be obtained by simple subtraction. All ranches in the valley are labelled on topographic maps, making accurate surface elevations for their wells also easily obtainable. The probe wire is numbered every five feet, with intermediate values determined using a tape measure. Depth to water was observed to the nearest inch, then rounded and recorded to the nearest foot.

Results of Water Table Data

Initial ground-water data was obtained from the U.S. Geological

A.

B.

Figure 9. Photographs of the acquisition of ground-water data.
A.) Precise water-table measurement being taken from a drill hole. B.) Probe used to obtain depth to water measurements.

Survey, Water Resources Division log file that records data on all drilling projects by latitude-longitude boundary specifications. Of these, 30 were found to contain water-level information that was in the study area and interpretable (Table IV). Legible logs are included in Appendix A. Water-level elevations were determined for 28 of the locations, enabling the construction of a preliminary potentiometric surface map for the basin (Figure 10). Depth to water ranged from 8 ft. in a well next to Kelly Creek to 280 ft. in a drill hole near the Pinson Mine. These data show that water-level elevations tend to mimic local topography and are at lower elevations but at shallower depths in the basin than in the bordering mountain ranges. Elevations of the water table reach 7,438 ft. in the Osgood Mountains, yet lie below 4,450 ft. in the lower parts of the mid-valley. The 7,438 ft. water table elevation is believed to be either structurally related or erroneous, since it is considerably higher than any other recorded value for the area. A flow net, constructed from the potentiometric surface map, shows two components of flow in the basin (Figure 11), including a lateral flow towards Kelly Creek and a southward flow to the Humboldt River.

Over half of the log localities are from the western side of the basin, owing to mining activity in the Osgood Mountains. In the vicinity of log sites 14 through 19, flow lines are thought to represent pumping effects of mine wells and/or preferential flow in permeable gravel.

The western border of the basin appears to have a steeper ground-water gradient than the eastern border. If true, then the ground water contribution to the valley-fill from the Osgood Mountains could be substantially more significant than the Snowstorm Mountain contribution. Thinner aquifers, less permeable units, or both could also produce wa-

TABLE IV

WATER TABLE DATA FROM THE WATER RESOURCES DIVISION LOG FILE

Log Number	Site Elevation(ft)	Depth to Water(ft)	WT Elevation(ft)
1	4559	26	4533
2	4559	48	4511
3	7546	108	7438
4	4904	30	4874
5	4511	15	4496
6	4854	23	4831
7	4526	76	4450
8	4543	28	4515
9	4461	28	4433
10	4526	12	4514
11	4461	10	4451
12	5100	27	5073
13	4953	246	4707
14	4838	85	4753
15	4788	221	4567
16	5051	280	4771
17	5100	196	4904
18	4805	210	4595
19	4915	168	4747
20	5248	212	5036
21	-----	Dry	-----
22	5051	126	4925
23	5035	182	4853
24	5592	46	5546
25	-----	---	-----
26	5051	8	5043
27	4920	190	4730
28	4920	180	4740
29	4789	74	4715
30	4723	24	4699

See Appendix A for actual logs of numbers 5, 8, 12, 14, 16, 18, 20, 23, 26, and 29

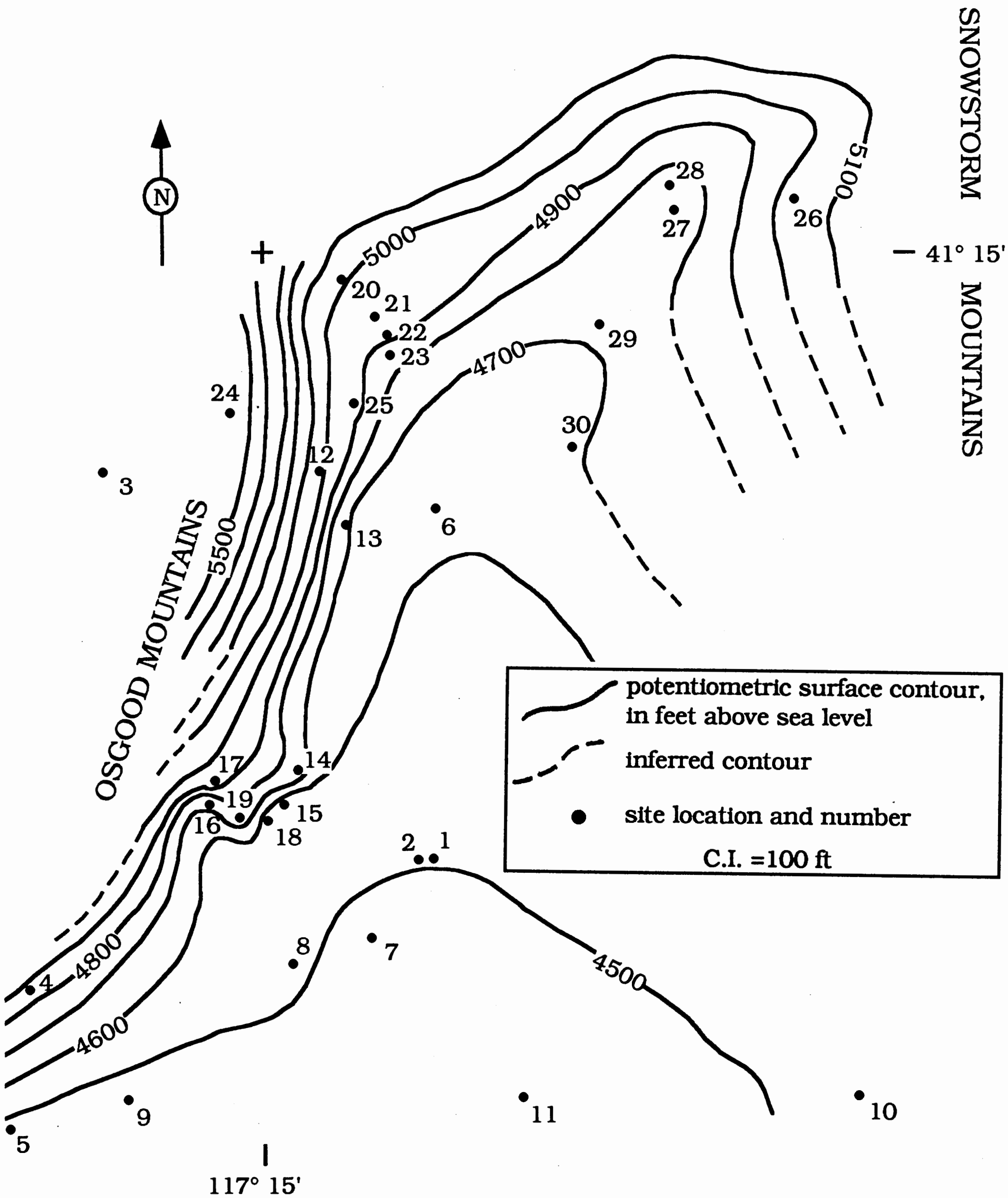


Figure 10. Potentiometric surface map based on USGS-WRD logs.

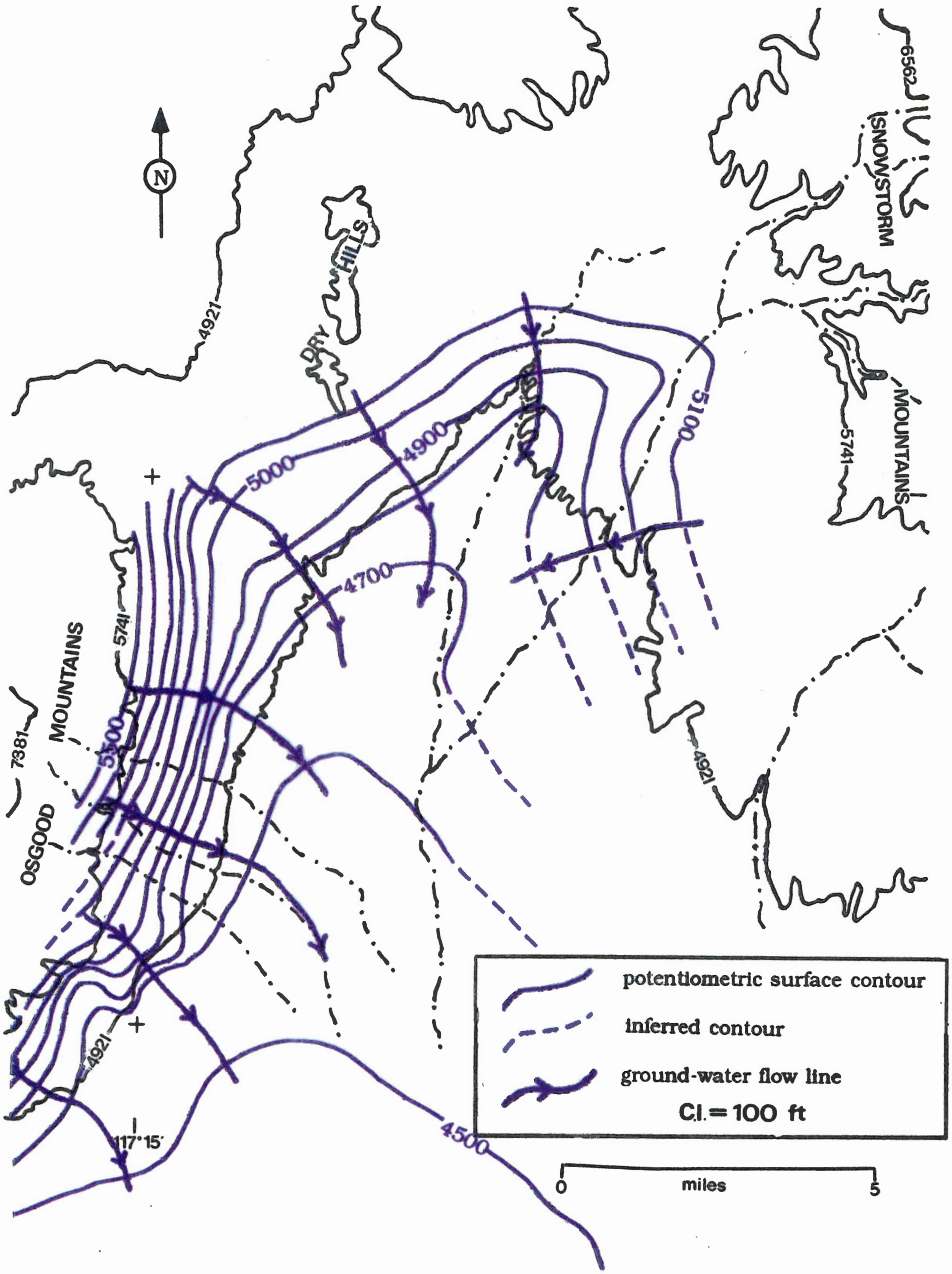


Figure 11. Flow net based on USGS-WRD data.

ter-level contours of this nature. However, ground-water data in the Snowstorm Mountains is too limited for definite confirmation at this time.

A second potentiometric surface map was constructed based on data collected on three separate visits by the author to the study area. The visits took place in late June 1990, mid February 1991, and early June 1991, and the accumulated data are listed in Table V. The potentiometric surface map for these data (Figure 12) is markedly similar to the map based on the WRD logs. This indicates that overall ground-water flow within the basin, despite discrepancies in sampling times, remains essentially unaltered by annual and seasonal fluctuations (Figure 13). During the acquisition of water-level elevation measurements, seasonal variation did exist, but it was always less than 10 ft. unless in the vicinity of a pumping well. Sites BAC-4, DE-36, SEE-367, and 90-74 are but a few of the drill holes that were measured at more than one time to test seasonal fluctuations of the water table.

For the collected data, the water table again mimicked topography with ground-water flow moving laterally towards Kelly Creek and southward to the Humboldt River. Depth to water ranged from 3 ft. between Summer Camp and Julian Creeks to 469 ft. west of Gold Field's Mining. The highest water-level elevation, 5,679 ft., was recorded at sample site 89-120 in the Osgood Mountains. The lowest, at 4,450 ft., was measured in ranch well BAC-5 located in mid-valley.

A large cluster of data exists in the north-central part of the potentiometric surface map between the 4,600 and 4,700 ft. water-level contours (Figure 12). This is the site of two open pit gold mines that have removed over 300 ft. of alluvial overburden to reach auriferous bedrock.

TABLE V

WATER TABLE DATA MEASURED FROM WELLS AND DRILL HOLES, THIS STUDY

Sample #	Site Elevation(ft)	Depth to Water(ft)	WT Elevation(ft)
88-40	4911	230	4681
88-104	4940	259	4681
89-120	5723	44	5679
89-211	4846	157	4689
89-212	4889	208	4681
89-215	4876	194	4682
89-224	5094	423	4671
90-2	5150	469	4681
90-3	5109	427	4682
90-5	5035	364	4671
90-74	5243	3	5240
BAC-1	4682	62	4620
BAC-2	5029	8	5021
BAC-3	4899	164	4735
BAC-4	4907	5	4902
BAC-5	4463	13	4450
BAC-6	4480	20	4460
BAC-8	5174	11	5163
BAC-9	5440	40	5400
DE-36	4890	207	4683
MURD-3A	4527	58	4469
MURD-3B	4500	27	4473
MURD-90-B1	4527	59	4468
MURD-90-B2	4588	125	4463
OW1	4903	246	4657
OW2	4969	343	4626
OW3	4919	274	4645
OW4	4778	102	4676
PIN-5A	5213	252	4961
PM90-22-2A	4950	310	4640

TABLE V (Continued)

Sample #	Site Elevation(ft)	Depth to Water(ft)	WT Elevation(ft)
R-72	4953	277	4676
R-90	4946	270	4676
R-200	4865	190	4675
R-298	4842	160	4682
RCH-876	5003	353	4650
RW-5	4795	109	4686
SEC-53	4987	347	4640
SEC-146	5085	430	4655
SEC-182	4801	111	4690
SEE-367	4988	355	4633
SEE-630	4805	128	4682
SEE-647	4795	114	4681
VEK-88-8-9	4829	113	4716
VEK-88-8-12	4688	178	4510
VEK-88-8-16	4791	110	4681

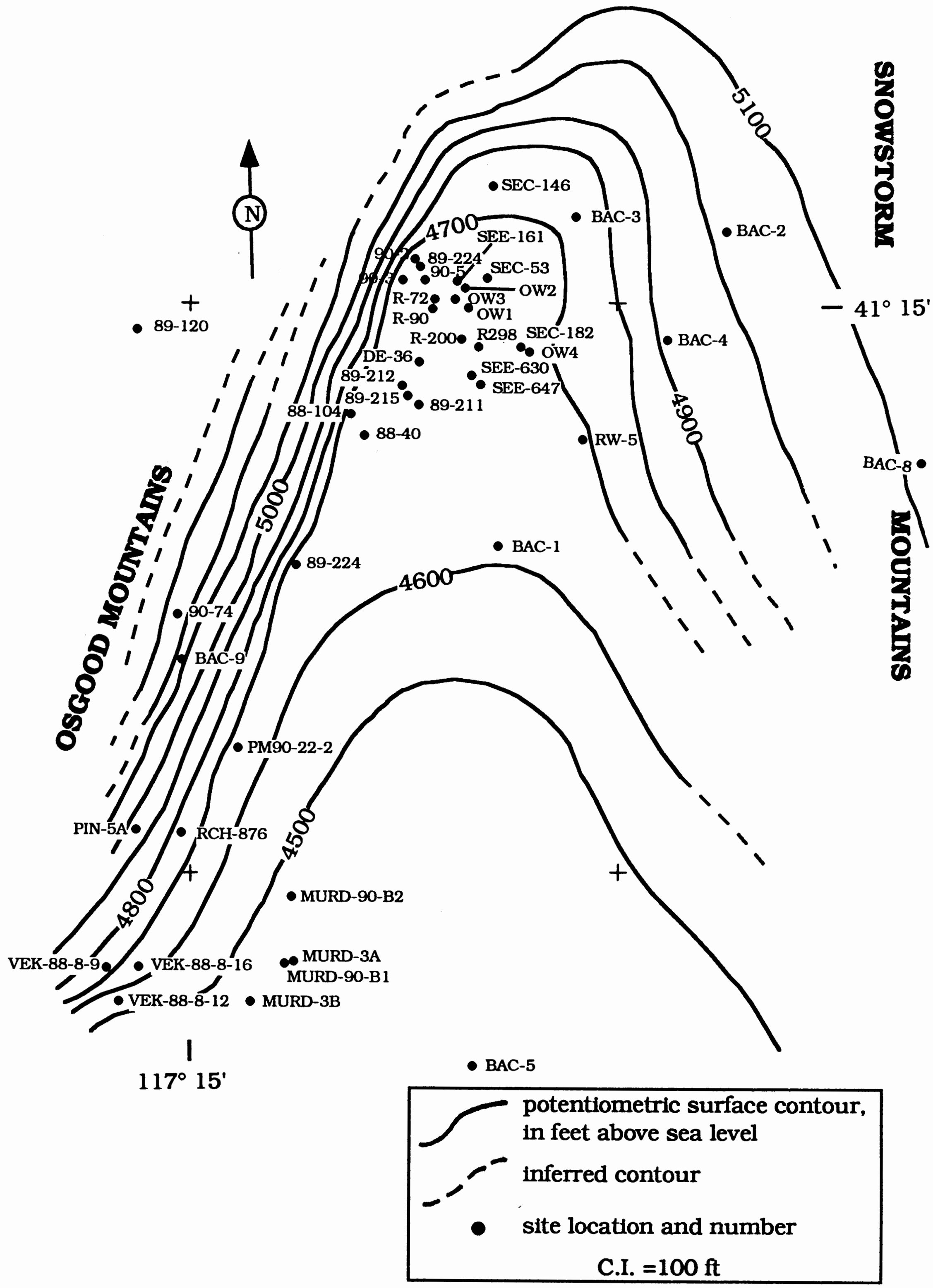


Figure 12. Potentiometric surface map based on measured water-levels.

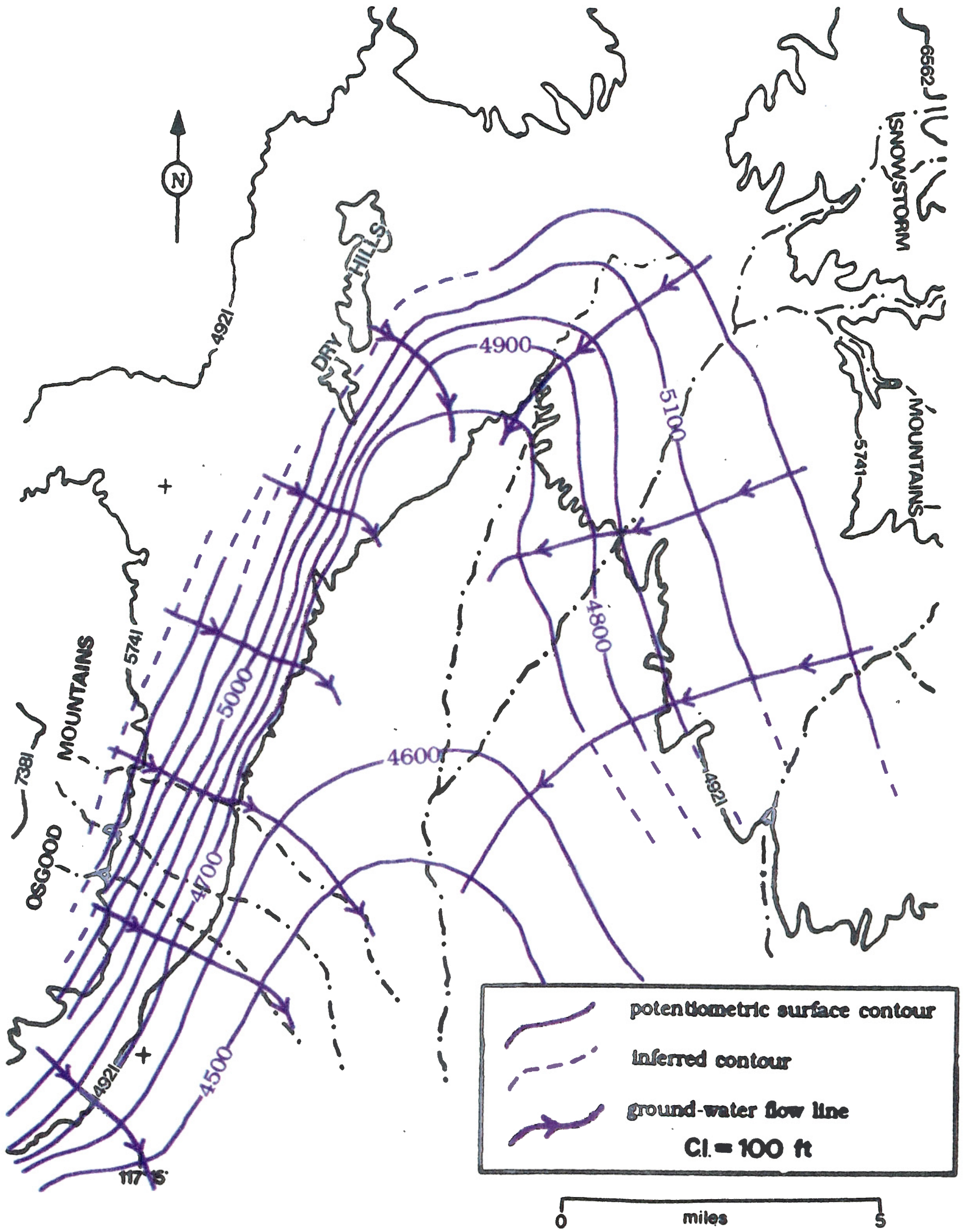


Figure 13. Flow net based on measured water-levels.

Fairly intense dewatering operations have resulted in the lowering of the water table in this area. It can be noticed that mine observation wells OW1, OW2, and OW3, at 4,657 ft., 4,626 ft., and 4,645 ft., respectfully, are all significantly lower in elevation than the surrounding measurements that hover around 4,680 ft. This represents a cone of depression in the vicinity the southernmost pit.

Sample site 90-74 occurs at a surface elevation of 5,243 ft. on the rising eastern face of the Osgood Mountains. Normally the depth to water would be greater under topographic high regions and lower under topographic low regions. At this location, however, depth to water is only 3 ft. It is believed to represent a structurally related localized flow path.

It should be noted that not all of the sample site water-level elevations fit perfectly within the contoured potentiometric surface maps of Figures 10 and 12. This is due to particular data points being inconsistent with surrounding sample sites. In Figure 12, a possible reason for the discrepancies is that depth to water values for sites BAC-6, BAC-9, RCH-876, and SEC-146 were obtained by word of mouth from ranchers and miners.

CHAPTER V

THEORY OF ENVIRONMENTAL ISOTOPE INVESTIGATIONS

General

Isotopes are atoms of the same element that have the same number of protons and electrons, but a different number of neutrons. There are 92 natural elements that give rise to more than 1,000 stable and radioactive isotopes.

In the use of isotopes, only the ratio of the heavy isotope to the light isotope of the same element is required, thus the absolute concentrations of each isotope are not needed (Ingraham, 1982). This is advantageous considering that in most cases ratios can be determined about an order of magnitude more precisely than absolute abundances.

Radioactive isotopes have nuclei that give out radiation and thereby change to nuclei of other elements (Krauskopf, 1979). The nuclei which result from radioactive decay, but do not themselves decay, are called radiogenic isotopes. Since radioactive isotopes decay at a constant rate, their use in the age dating of rocks has been vital. If no alteration of the parent-daughter ratios has occurred after initial formation, the ratios can be used to calculate ages. Also, trace element radiogenic isotope ratios of waters are diagnostic of the source material with which the waters interact. Therefore, they can be used as tracers of solute sources given the right geologic conditions.

Stable isotopes are nuclei that do not undergo radioactive decay.

For isotopes in the water molecule, variations in composition are usually created when fractionation occurs during evaporation and condensation. Since the isotopes of water do not break down, once meteoric water infiltrates into the ground-water system, the isotopic signature is set unless certain subsurface processes occur to change the signature. These include, for example, geothermal activity that causes water-rock isotopic exchange; or extreme chemical conditions, such as low pH, that may enable dissolution of otherwise insoluble rocks and minerals. Since these conditions are not typical in most ground-water systems, stable isotopes can be a valuable tool in determining recharge areas, discharge areas, mixing, and flow paths in local and regional settings.

Stable Isotopes

General

The water molecule can consist of five stable isotopes from two elements: two of hydrogen (^{1}H or H, protium; and ^{2}H or D, deuterium) and three of oxygen (^{16}O, ^{17}O, and ^{18}O). The average abundances for each are listed below:

^{1}H:	99.9844%	^{16}O:	99.763%
D:	0.0156%	^{17}O:	0.0375%
		^{18}O:	0.1995%

where $^{18}O/^{16}O$ is the ratio used for oxygen because ^{18}O is more common than ^{17}O (Way and others, 1950; Garlick, 1969 in Hoefs,1987). Ratios are expressed in parts per thousand (per mil - ‰) difference from a worldwide standard called standard mean ocean water (SMOW). SMOW is used because its hydrogen and oxygen isotopic composition remains relatively constant.

Variations from SMOW are signified by δ (delta) where

$$\delta_{heavy} = \frac{R_{sample} - R_{standard}}{R_{standard}}(1000)$$

and R represents D/H or $^{18}O/^{16}O$. If δ is negative then the water is considered depleted in the heavy isotope relative to SMOW. It is also referred to as being isotopically light. An enrichment in the heavy isotope is signified by a change towards a positive δ value, with the corresponding water considered isotopically heavy.

Fractionation

The partitioning of isotopes between two substances or phases, such that the substances or phases have different isotope ratios, is called *isotope fractionation*. The fractionation factor is defined by:

$$\alpha = \frac{R_a}{R_b}$$

where R_a is the ratio of concentrations of the heavy to light isotope in phase A, and R_b is the same ratio in phase B. For example, in $\alpha_{H_2O\ liquid\text{-}vapor}$ R_a is $^{18}O/^{16}O$ in liquid water, and R_b is $^{18}O/^{16}O$ in water vapor. At 25°C, given equilibrium conditions, the value of $\alpha_{H_2O\ liquid\text{-}vapor}$ is approximately 1.0092. This means that $\delta^{18}O$ of liquid water would be enriched by about +9‰ relative to the water vapor.

Isotopic fractionations are temperature dependent. At infinitely high temperature, all isotopic species are well mixed and isotopic fractionation factors are 1.0000. At the earth's surface, temperature fluctuations resulting from changing climatic conditions of a region can cause significant variations in the isotopic composition of waters.

Since the isotopes of hydrogen and oxygen are intimately related in the water molecule, isotopic fractionation of both is usually covariant. Hence, the isotope ratios of the two are commonly discussed together.

The different isotopes of hydrogen and oxygen behave differently based on their differences in vapor pressure. This results from deuterium being heavier than protium and ^{18}O being heavier than ^{16}O. The lighter isotopes will preferentially enter the vapor phase while the heavy isotope will tend towards the condensate. The effect is illustrated in the isotopic composition of precipitation from a storm system as it moves inland from the coast. Ehhalt and others (1963) called it the 'continental effect' and stated that as a storm undergoes several episodes of precipitation, the remaining vapor will become progressively depleted in the heavy isotopes (Figure 14). Ingraham and Taylor (1986) show the isotopic changes in δD along a west to east transect from the Pacific coast of northern California to the northern Great Basin in Nevada; i.e. water samples become steadily depleted with distance inland (Figure 15).

Values of SMOW are 0‰ for both δD and $\delta^{18}O$. Comparisons from these values are made because the ocean is the ultimate source and sink for the hydrologic cycle. The water vapor above the ocean is slightly depleted in the heavy isotopes due to fractionation during evaporation. During condensation of the water vapor, the heavy isotopes are concentrated in the precipitation while the remaining water vapor becomes progressively lighter (Figure 14). However, individual rainfalls at any particular site can show widely scattered isotope compositions, with small showers commonly exhibiting the most divergent values (Gat, 1971).

The process of rain evaporating as it falls affects the isotopic signa-

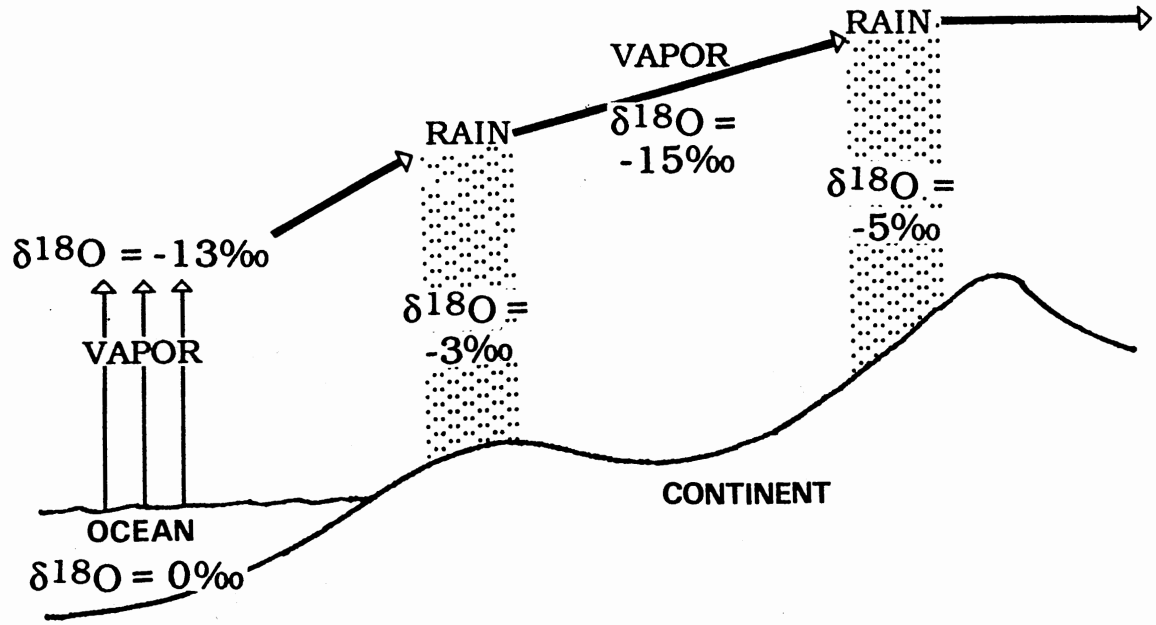


Figure 14. Isotopic fractionation of $\delta^{18}O$ in precipitation as a storm system travels inland from the ocean (Modified from Siegenthaler, 1979).

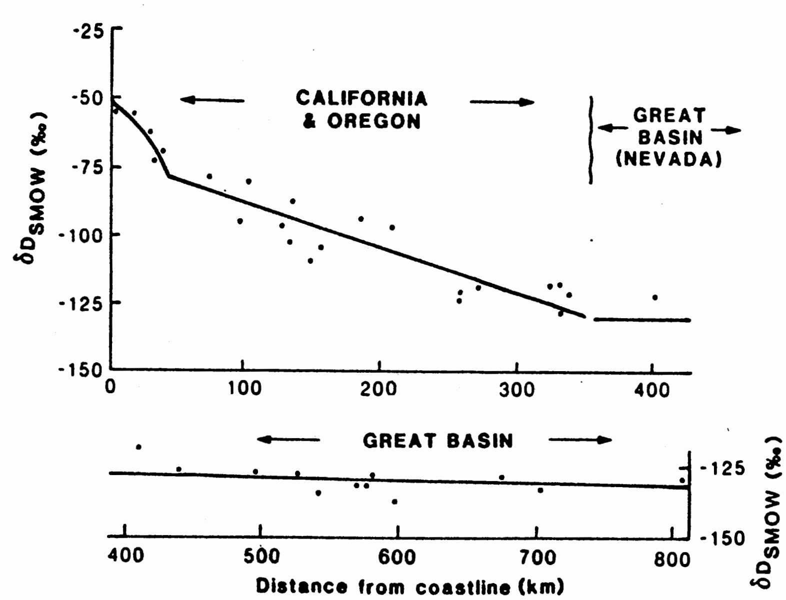


Figure 15. Changes in δD of water samples along a west-east transect from the Pacific Ocean to the northern Great Basin (Modified from Ingraham and Taylor, 1986).

ture of precipitation. In arid regions, precipitation can show significant enrichment in the heavy isotopes from evaporation during falling (Gat, 1971). However, the isotopic composition of snow does not shift due to evaporation during falling. This characteristic could aid in determining the isotopic compositions of recharge waters within the Kelly Creek Basin.

Once precipitation percolates into the ground, isotopic fractionation generally ceases. Also, the isotope composition of circulating ground waters is virtually unchanged during its passage through the aquifer, by virtue of the large bulk of the water mass compared to that of the surface material with which it comes in contact, and the sluggishness of the solid state reactions (Gat, 1971). This conservation of the isotope composition in ground waters generally holds true even for waters that are some tens of thousands of years old (Gat, 1971). Therefore, the atmospheric history of precipitation will be reflected in the isotopic signature of the ground water.

Interpretation

The relationship between δD and $\delta^{18}O$ is often represented by the following equation:

$$\delta D = 8\delta^{18}O + 10$$

referred to as the meteoric water line on a δD-$\delta^{18}O$ plot. Craig (1961) studied the isotopic compositions of meteoric water, i.e. water of recent atmospheric origin, from around the world in formulating the above relationship.

Under equilibrium conditions (i.e., when fractionation results only from vapor pressure differences between the isotope species (Gat, 1971)), cyclic changes in precipitation during evaporation and condensation maintain an isotopic composition that plots on a line with a slope of 8 (the slope of the MWL). In arid climates of high temperature and low humidity, however, nonequilibrium conditions produce slopes in the vicinity of 6. At extremely high temperatures (70-90°C) or very low humidity (<20%) the slope can be as low as three (Ellis and Mahon, 1977 in Ingraham, 1982)

Dansgaard (1964) used d (deuterium excess parameter) to signify the surplus or lack of deuterium relative to the MWL. Changes in the d-parameter are reflected by changes in the δD-intercept on a δD-$\delta^{18}O$ plot. Water that plots above the MWL has a positive d, and water that plots below the MWL has a negative d (Figure 16). Although equilibrium conditions do not cause changes in the d parameter during evaporation or condensation, non-equilibrium conditions cause significant fluctuations.

Isotope compositions of partially evaporated waters are characterized not only by high δ values, but also by their d values. Consider a water of the isotopic composition at A in Figure 16. A non-equilibrium evaporated water will plot on a line with a slope of less than 8, and will extend towards the negative d parameter side of the MWL (Figure 16). This characteristic is the basis for recognizing the contributions to ground-water systems from surface waters and precipitation that have been subjected to evaporation (Gat, 1971). If a condensate forms under non-equilibrium conditions, the slope of the resulting line will again be less than 8, but it will plot on the positive d parameter side of the MWL (Figure 16).

The effects of climatic conditions in some regions cause a deviation

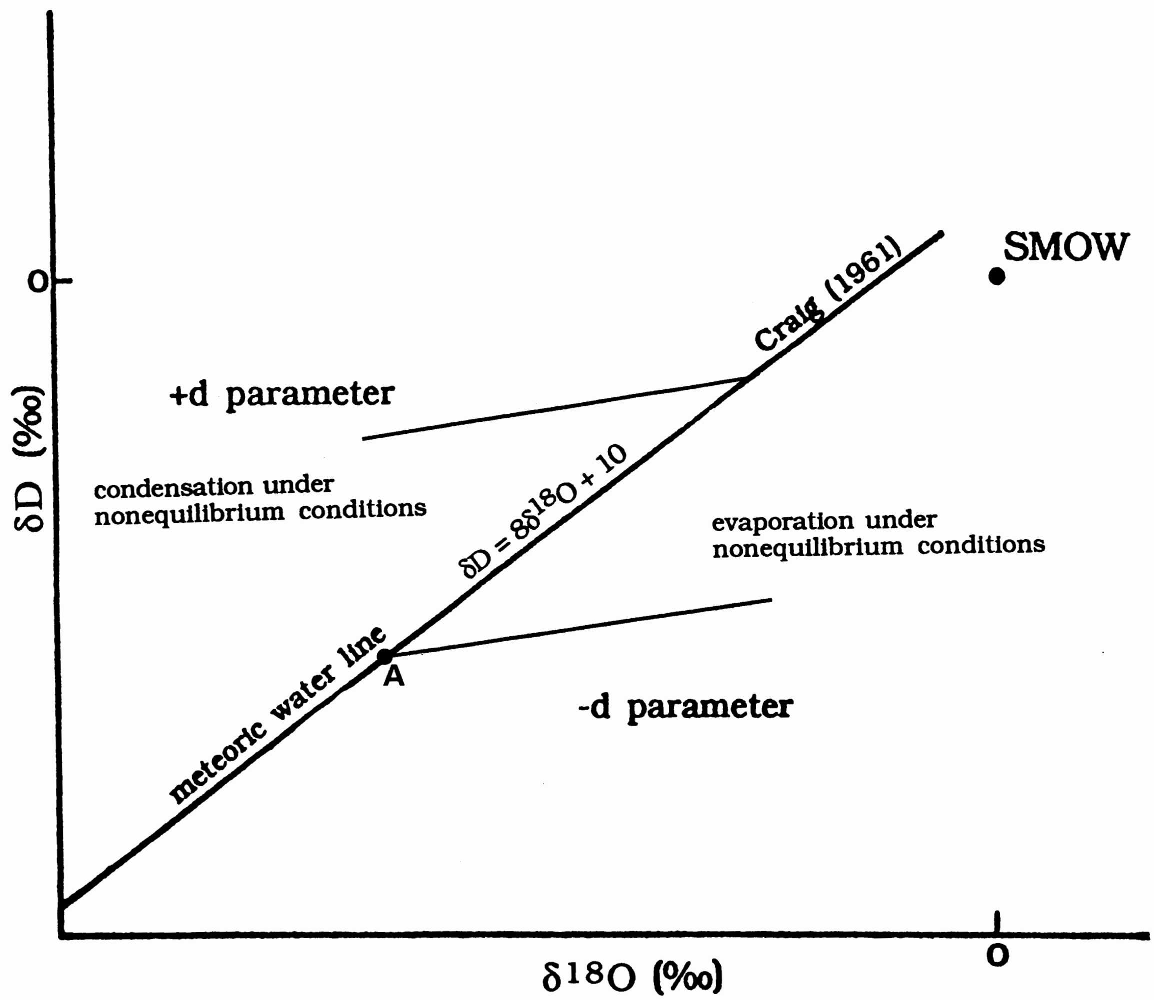


Figure 16. δD vs. $\delta^{18}O$ plot showing deuterium excess parameters in relation to the meteoric water line.

in isotopic composition from the MWL, such that a local meteoric water line (LMWL) is developed. This line represents the isotopic composition of meteoric water existing in a particular area. In semiarid and arid climates, precipitation and ground waters are very depleted in heavy isotopes, resulting in isotopic compositions that can significantly deviate from the MWL. The northern Great Basin climate produces waters that reflect this phenomenon.

Increasing elevation and latitude generally produce lighter δ values for D and ^{18}O in precipitation. These values also tend to become lighter inland from the coast and at lower temperatures (Figure 17). Therefore, precipitation in the winter at high elevations is depleted relative to precipitation in the summer at lower elevations. These characteristics result in recharge waters (high elevation) being isotopically depleted relative to waters falling in the valley proper.

Tritium

Tritium (^{3}H or T) is a naturally occurring radioactive isotope of hydrogen with a half-life of approximately 12.4 years. Its natural production results from cosmic ray interactions with nitrogen in the atmosphere, but far greater amounts were produced anthropogenically by thermonuclear weapons testing between 1953 and 1963. The standard measurement of tritium is the tritium unit (TU) where 1 TU = one tritium atom per 10^{18} atoms of ^{1}H.

The prebomb level of tritium in precipitation was about 10 TU but this number is uncertain due to the sparsity of data prior to 1953 (Drever, 1988). Kaufman and Libby (1954) state that natural (prebomb) levels of tritium were about 0.5 TU for the surface ocean, and between 1

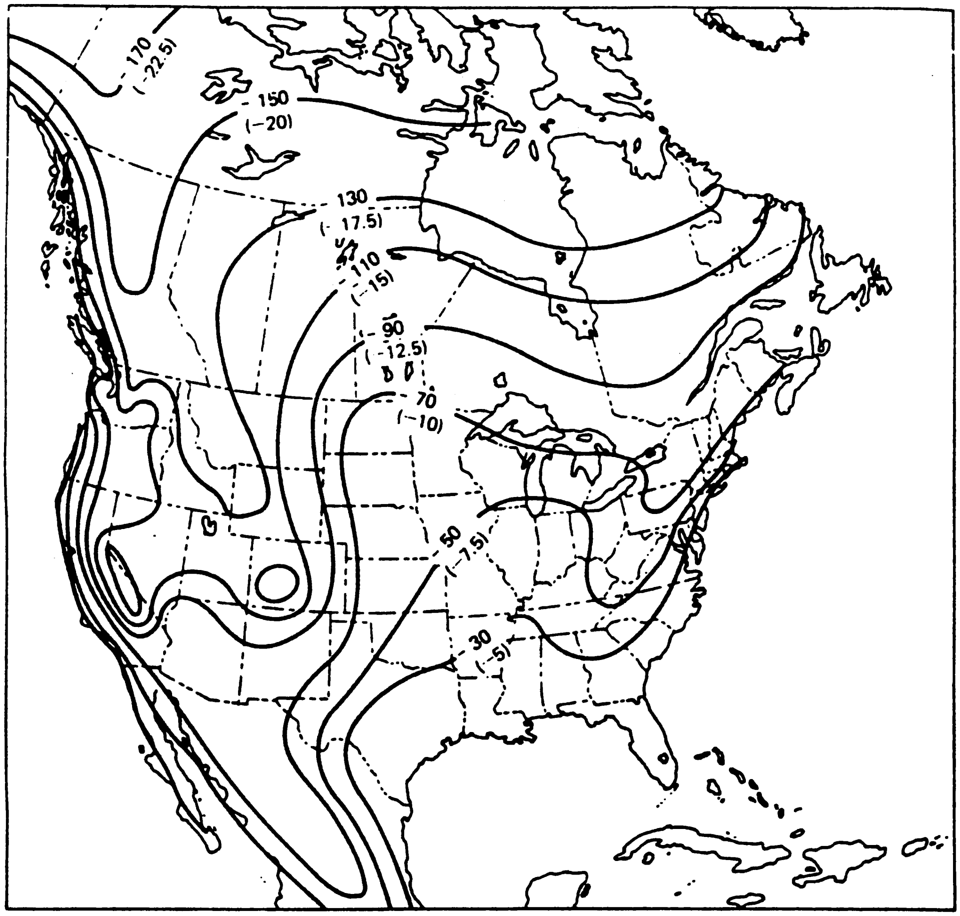


Figure 17. Distribution of δD and corresponding $\delta^{18}O$ (in parentheses) in meteoric waters in North America (Modified from Sheppard and others, 1969).

and 20 TU for continental precipitation. These natural levels, however, were overwhelmed by the anthropogenic concentrations introduced as a result of thermonuclear weapons testing. This testing induced tritium, which combined with atmospheric O_2 to form tritiated water vapor ($^1H^3HO$ or HTO), was easily incorporated into precipitation (Philips and others, 1988). As a result, tritium concentrations in precipitation increased two to three orders of magnitude (Michel, 1989), and surface ocean waters reached 50 TU (Koide and others, 1982 in Michel, 1989). Being a part of the water molecule, tritium rapidly entered the hydrologic cycle in quantities far exceeding previous levels. This 'bomb spike' provides the basis for tritium's use in ground-water studies. The tritium content of the output of a ground-water system depends on that of the input, and on the residence time and type of flow in the system (Pearson and Truesdell, 1978). Therefore, water that infiltrated into the ground-water system during peak tritium periods exists as a marker for tracing flow and mixing patterns. Tritium is best used to study processes that occur on a timescale of 10 to 100 years (Michel, 1989). In cycles longer than this, the bomb transient factor will no longer be valid due to decay.

Radiogenic Isotopes

General

Lead and strontium consist of both radiogenic and nonradiogenic isotopes. The ratios of radiogenic to nonradiogenic constituents have been used for a variety of geologic studies, most notably in the dating of rocks and minerals. Another valuable use relates to the fact that the minor and trace element isotopic signatures of waters are characteristic of the rocks with which they are in contact (Andreyev and others, 1967;

Fisher and Stueber, 1976). This tracer characteristic is the premise used in attempts to follow ground-water flow in regions where distinctive lithologies exist.

Lead

There are three radiogenic isotopes of lead: ^{206}Pb, ^{207}Pb, and ^{208}Pb. The formation of each is related to the radioactive decay of ^{238}U, ^{235}U, and ^{232}Th, respectively. The reactions responsible for the decay are as follows:

$$^{238}U \longrightarrow {}^{206}Pb + 8He + 6B^-$$

$$^{235}U \longrightarrow {}^{207}Pb + 7He + 4B^-$$

$$^{232}Th \longrightarrow {}^{208}Pb + 6He + 4B^-$$

where each helium nuclei consists of 2 protons and 2 neutrons and each B^- represents beta decay of one electron. The nonradiogenic isotope of lead is ^{204}Pb, and the corresponding ratios used in geologic studies are $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$. Because the heavier isotopes are produced by radioactive decay, they have increased in abundance relative to the nonradiogenic and lighter ^{204}Pb throughout geologic time.

Most work with lead is based on graphical comparisons of $^{206}Pb/^{204}Pb$ to $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ to $^{208}Pb/^{204}Pb$. These diagrams can illustrate trends of enrichment and depletion among samples. Isochrons are lines that connect samples of variable composition. The slope of the isochron dictates the age of the system with increasing slopes indicating older ages. The geochron is the zero isochron and connects the compositions of primeval lead obtained from meteorites

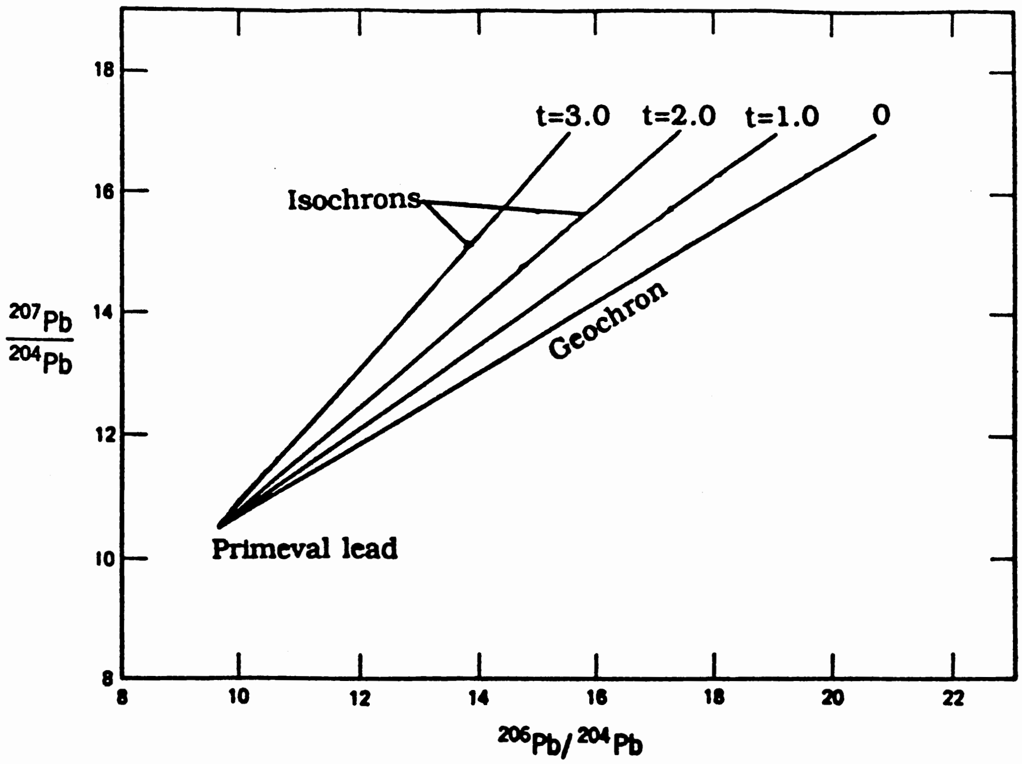


Figure 18. $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ plot showing primeval lead, the geochron, and isochrons (Modified from Faure, 1977).

(Figure 18).

There is considerable variability in lead ratios within most geologic rock suites. Young mantle-derived volcanic rocks commonly plot to the right of the geochron on a $^{206}Pb/^{204}Pb$ vs. $^{207}Pb/^{204}Pb$ diagram. This indicates an enrichment in ^{206}Pb relative to ^{207}Pb. High $^{207}Pb/^{204}Pb$ ratios generally indicate an older crustal igneous and metamorphic rock source. Old mid to lower crust can have a low U/Pb ratio but a high $^{207}Pb/^{204}Pb$ ratio. Old upper crust has higher U/Pb ratios, and is generally enriched in ^{206}Pb. This is because ^{235}U decays to ^{207}Pb faster than ^{238}U decays to ^{206}Pb.

$^{206}Pb/^{204}Pb$ ratios in aeolian materials generally range between 18.6 and 18.8 over the U.S., with variations occurring based on geographic location. Igneous rock and limestone components raise the ratio to 19.0-19.5. Ratios greater than 19.5 need an old uranium-rich source rock. In many instances, this source is limestone.

Strontium

Strontium isotope systematics are based on the increases over time of ^{87}Sr as a result of the beta decay of ^{87}Rb. The reaction is as follows:

$$^{87}Rb \longrightarrow {}^{87}Sr + B^{-}$$

The nonradiogenic isotopes of strontium are ^{84}Sr, ^{86}Sr, and ^{88}Sr. Variations in the $^{87}Sr/^{86}Sr$ ratio are used to study rocks and water.

A brief synopsis of earth history will aid in the understanding of strontium ratios. It is a generally-accepted view that early in geologic time, the elements making up the earth differentiated, concentrating silicates of iron and magnesium in the upper mantle, and concentrating silica, alumina, and alkali metals in the crust. Rubidium, a Group IA element of the Periodic Table and alkali metal, forms the large and singly charged Rb^{+} ion. It behaves similarly to K^{+} and is concentrated in silica-rich magmas that are prevalent in the crust. Strontium however, is a Group IIA alkaline earth element of the Periodic Table that forms the doubly charged Sr^{2+} ion. Its chemical behavior resembles that of the Ca^{2+} ion and is, therefore, more prevalent than rubidium in the upper mantle. The $^{87}Sr/^{86}Sr$ ratios then, should be higher in crustal material than in mantle-derived material. The $^{87}Sr/^{86}Sr$ ratio, therefore, can be used to discriminate magmas which originated by partial melting of mid to lower crust from magmas which originated by partial melting of the mantle or mantle-derived basalts in the lower crust.

Typical $^{87}Sr/^{86}Sr$ ratios of mantle-derived material are obtained from oceanic basalts that have had little to no interaction with crustal material. These ratios generally fall between 0.702 and 0.706; the range indicating a source that is not homogeneous (Krauskopf, 1979). Continental crustal material and its weathering products, however, contain rocks with high Rb/Sr ratios resulting in $^{87}Sr/^{86}Sr$ ratios that are commonly greater than 0.710.

The isotopic composition of strontium is a reflection of the strontium isotopic composition of the rocks with which the water has interacted. This characteristic exists for both surface water and ground water. Fisher and Stueber (1976) found that stream waters in Maryland and Pennsylvania which flow over a particular lithology reflect the $^{87}Sr/^{86}Sr$ signature of that rock type. They were able to correlate $^{87}Sr/^{86}Sr$ signatures of bedrock and stream waters throughout the Susquehanna River Basin. However, Chaudhuri and others (1987) measured $^{87}Sr/^{86}Sr$ ratios of 0.7225 in ground water in Kansas, unlike the carbonate rocks with which the water was in direct contact which had a $^{87}Sr/^{86}Sr$ ratio of 0.709. The high $^{87}Sr/^{86}Sr$ water ratio was found to reflect interaction of the ground water with Precambrian crystalline rocks upgradient that contained abundant alkali feldspar, and hence, abundant rubidium and ^{87}Sr. Evidently, the rock must be capable of providing strontium to the water. Weathered silicate minerals, especially clays, exchange readily with water, whereas exchange with limestone occurs via dissolution.

CHAPTER VI

ISOTOPE SAMPLE COLLECTION AND ANALYSIS

Sample Collection

Kelly Creek Basin water samples were collected on two of three visits to north-central Nevada. All collected waters were analyzed for the stable isotope of hydrogen. Limited samples were analyzed for the isotopic composition of oxygen, strontium, lead, and tritium. On a February 1991 visit, attempts were made to acquire snow samples at different elevations in order to determine isotopic signatures of recharge waters. This resulted in limited success, as there were unusually low amounts of snow accumulation. In fact, warmer than normal temperatures allowed for intermittent rain showers to occur. Well and drill hole samples were also collected in February with most sites coming from mining company properties. In June 1991, remaining ranch wells, and spring and stream samples were obtained. Spring and stream samples were generally located on the rising faces of the bordering mountain ranges.

There was an attempt to collect samples from widely spaced locations so as to get even coverage throughout the basin. However, the sparsity of available sampling localities on the east side of the valley floor and in the Snowstorm Mountains caused coverage to be thinner in this area. Abundance of drill holes and access from mining roads allowed for denser sampling to take place in and adjacent to the Osgood Mountains. The area around Rabbit Creek is the site of two open pit gold mines.

A.

B.

Figure 19. Photographs of sampling procedures. A.) Bailer used to acquire ground water samples in wells and drill holes. B.) Tripod used to filter samples via a peristaltic pump.

Numerous drill holes and observation wells in this region result in the best sample coverage in the valley.

A total of 37 samples were collected. Of these, eight were taken from wells, six from drill holes, 10 from springs, nine from streams, three precipitation samples, and one from a water reservoir. Hydrogen isotopes were analyzed in all samples. Oxygen isotopes were measured in 11 samples, with four each coming from springs and drill holes, two from wells, and one stream sample. High costs for tritium analyses resulted in only three samples being processed, including one from each of the ranges and one from mid-basin. Strontium and lead samples were taken at 19 of the 37 sample sites, including springs, streams, wells, and drill holes. Strontium analyses were performed on all 19 of the samples, while only 12 samples were analyzed for the various lead ratios.

Sampling Procedure

General

Samples were taken from drill holes, wells, streams, springs, and precipitation. For wells and drill holes, an electric probe was used to ensure water existed within the hole. If so, a 1 liter bailer was lowered to a depth of 50-100 ft. below the top of the water column for sample acquisition (Figure 19). This was done to avoid sampling water that had undergone evaporative fractionation with the atmosphere. Since the bailer only holds 1 liter of water, and on numerous occasions it would not come up full, it was frequently necessary to lower it several times to obtain the needed quantity of sample. In many drill holes, desired sampling depths were not attainable due to the collapse of the hole below the water table. Wells, most notably at ranches, were commonly pumping so no bailer was needed for sampling.

At springs and streams, containers were submersed during filling and capped under water to minimize atmospheric influence. In many instances, flow at springs was so minimal or clogged by vegetation that sampling proved challenging. Often, conduits had to be constructed to enable flow from the ground orifice. Samples were taken as close to the orifice as possible and as quickly as possible to avoid evaporative fractionation.

Stable Isotopes

Hydrogen and oxygen samples were syringed through a 0.45 micron filter into a 35 milliliter (ml) glass bottle with a conical poly-seal cap. The filtering removed particulate and colloidal material from the sample. Approximately 10 ml of filtered sample water was used to rinse the bottle prior to filling and then discarded. The bottle was filled so that the meniscus stood just below the conical tip of the cap. As a precautionary measure, filling the bottle all the way to the top was avoided in case warming occurred that would cause expansion of the water and possible leaking. The bottle was held very steady and the cap was screwed on tightly. This eliminates turbulation prior to sealing, which keeps contamination from atmospheric vapor to a minimum.

Tritium

Tritium samples were collected in one liter glass bottles with conical inserts in the caps. Plastic bottles can be used but they are not reliable when dealing with low-level analyses. Samples were filtered through 0.1 micron filter paper located in a tripod stand using a peristaltic pump

(Figure 19). The pump is powered by a car battery using a cable hook up. Since flushing the sample bottles with argon (or nitrogen) prior to filling was not possible, rinsing was again achieved by using with a small amount of filtered sample. Bottles were filled in comparable fashion to that of the hydrogen and oxygen samples.

Lead and Strontium

A single sample was collected for both strontium and lead. The analysis requirement is that the water contains at least one microgram of strontium and 0.1 micrograms of lead. One liter, wide-mouthed, Nalgene containers were used for collection. These containers are permissible for lead and strontium because evaporative fractionation is not a concern with these elements. Samples were filtered with 0.1 micron filter paper in a tripod stand using a peristaltic pump as discussed for tritium samples. The filtering of lead and strontium samples is of utmost importance to insure that no particulate or colloidal material is present in the sample that would result in non-representative isotopic signatures. After filtration, samples were acidified to pH=2 using Ultrex nitric acid. Ultrex is an ultrapure acid that contains negligible trace constituents. By acidifying the samples no precipitation or filming would develop during transit of the water.

Precipitation Sampling

Precipitation sampled in Kelly Creek Basin includes snow and rain. Snow samples were taken using a homemade coring device. It consists of two pieces of PVC pipe, each about 4 ft. long, with one fitting inside the other. The larger diameter piece was cored into the snow perpendicular to the ground in order to sample numerous snowfalls. The smaller diameter piece was corked at one end and used to force the snow from the wider pipe. The isotopic signature of the snow core is a mixture of several snowfall events. This should represent the signature of the recharge of the system at a particular elevation.

The snow cores were placed in squeezable Nalgene containers and allowed to melt. As melting commenced, air was continually removed by squeezing the container. This was done indoors to minimize evaporative fractionation. Once the melting was complete, the samples were filtered and placed in 35 ml glass bottles in the same manner discussed for stable isotopes.

Due to logistical difficulties, no rain collector could be used to sample different storm events in the study area. Therefore, the only storm event sampled was a winter rain shower. A rain collector made from an ice chest was used to trap waters from a passing system. The water was immediately filtered and bottled using procedures described earlier.

Laboratory Procedures

Hydrogen

The determination of D/H ratios was performed at the U.S. Geological Survey Isotope Lab in Denver, Colorado. The method used converted water to H_2 gas by forcing a reaction with zinc at 500°C.

$$H_2O + Zn \longleftrightarrow ZnO + H_2$$

Samples were analyzed in a Finnigan mass spectrometer. Results are reported as δD_{SMOW} in ‰ where error is equal $\pm$ 1‰. Replicate analyses were performed on approximately 10 percent of all samples in order to check precision.

Sample preparation was done by the author and involved the following steps:

1. Cut 1/5 inch diameter glass tubes into 9 inch segments. The tubes are cleaned by placing them in an oven at 500°C for approximately 12 hours.
2. One end of the glass tube is then melted closed and filled with about 0.125 grams of zinc.
3. Prior to placing the zinc-filled glass into a vacuum, a small kink in the glass is placed 4 inches from the zinc-filled end.
4. Six sample chambers are available in the vacuum system. All six valves are closed before placing each individual tube into position. The valves are then opened one by one to remove atmospheric gases.
5. When pressure in the system has stabilized, each of the six slots are checked for leaks by closing all valves and opening each individually. If no leaks exist, no change will register on the pressure gage.
6. Valves remain open as a heating apparatus is placed at the bottom (zinc filled ends) of the glass tubes. This forces any remaining water vapor out of the system.
7. Liquid nitrogen is then poured into a six slot container that covers the zinc filled end of each of the glass tubes.
8. Valves are then closed and 3 microliters of water sample is syringed into each chamber individually. The sample freezes at the liquid nitrogen level of the glass tube. Samples remain in liquid nitrogen for 11 minutes. After 10 minutes, any condensation below the valve is heated slightly to drive the sample into the tube.
9. A torch is then used to close off and separate the portion of the tube containing the zinc and frozen water sample. The separated tube segments are approximately 5-6 inches in length.

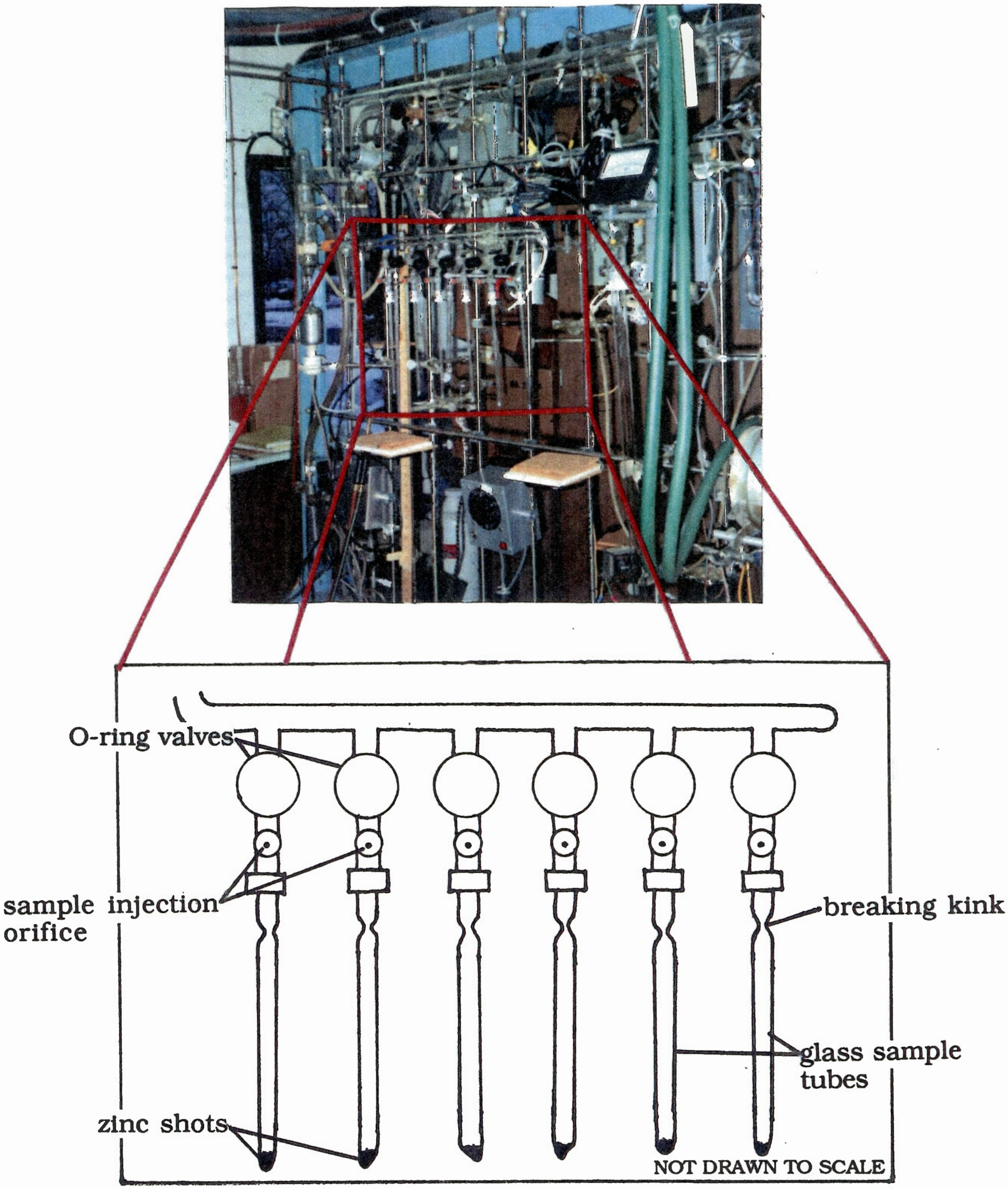


Figure 20. Laboratory setup used for hydrogen isotope sample preparation.

10. Once all six glass tubes are separated, they are placed in an oven at 500°C for 45 minutes. Heating drives the reaction between water and zinc to form hydrogen gas.
11. The H_2 gas in each of the tubes is then analyzed in the mass spectrometer. The samples are placed in six isolated chambers and each tube is broken at the kink. The gas is released, ionized, and collimated. The beam is deflected using an electromagnet with deflection radii dictating the isotopes measured in the ion detector cup.

The lab facilities used for the above process are shown in Figure 20.

Oxygen

The $^{18}O/^{16}O$ water ratios were prepared and analyzed by U.S. Geological Survey, WRD labs in Menlo Park, California. The technique involves the equilibration of CO_2 of known isotopic composition with a surplus of water sample. This method requires an exact fractionation value at a given temperature for $CO_2 \longleftrightarrow H_2O$. Aliquots of the CO_2 gas are analyzed in a mass spectrometer. Precision of the $\delta^{18}O$ determination is $\pm$ 0.1‰.

Tritium

Water samples were analyzed for ^3H by low-level gas proportional counters at The Tritium Laboratory at the University of Miami in Miami, Florida. A four step process including distillation, electrolytic enrichment, gas preparation, and low-level counting was used. Analyses are calculated in picocuries per liter with a detection limit of 0.3 pci/L. Commonly, tritium is expressed in tritium units (TU) where 1 TU = 3.2 pci/L. Conversions to TU have been made for tritium data in this study.

Lead and Strontium

Radiogenic isotopes are measured with best precision by solid-source mass spectrometric techniques. The U.S. Geological Survey, WRD in Menlo Park performed all analyses. Minimum concentrations of 1 microgram for strontium and 0.1 micrograms for lead are needed from each water sample. The following analysis description comes from Faure (1977).

A salt of the desired element is made and placed in the mass spectrometer on filament (composed of Ta, Re, or W). The filament is heated to a temperature sufficient to ionize the element to be analyzed (Pb or Sr). The resulting ions are accelerated by an adjustable voltage and collimated into a beam by means of suitably spaced slots. The beam enters a magnetic field generated by an electromagnet. The field deflects the ions into paths proportional to the masses of the isotopes, that is, the heavier ones are deflected less than the light ones.

CHAPTER VII

ISOTOPE RESULTS

General

Stable and radiogenic isotopic compositions were determined to assess the hydrogeologic conditions within the Kelly Creek Basin. Samples of precipitation, surface water, and ground water were used in constraining recharge areas, discharge areas, and flow paths of the ground water system. All reservoir, rain, snow, spring, and stream samples can be delineated by the suffixes RV, RN, SN, SP, and ST, respectively, in their site names. Other site names represent drill holes or wells. The locations of all isotope samples are shown in Figure 21 with sampling dates and isotope values listed in Appendix B.

Stable Isotopes

Precipitation

Precipitation was analyzed in an attempt to establish the isotopic composition of waters feeding the ground and surface water system within the basin. Logistical problems enabled the collection of only three precipitation samples from Kelly Creek Basin. Two were snow cores from the Snowstorm Mountains and one was a passing rain shower in mid-valley, all of which were obtained in the winter.

Sample RC91RN was collected at an elevation of 4,921 ft. and has a δD=-95‰. Samples RC91SN1 and RC91SN2 were obtained from

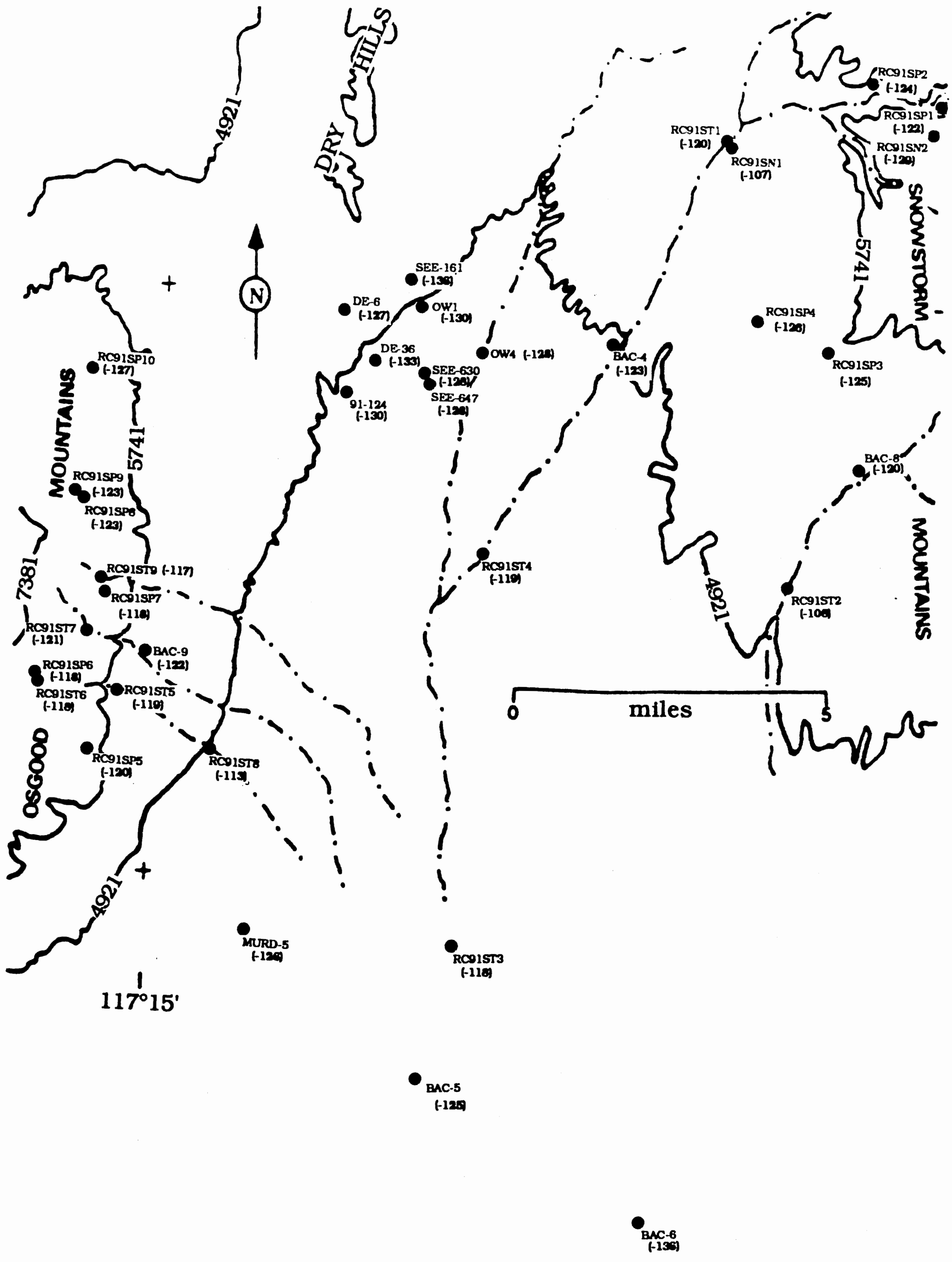


Figure 21. Isotope sample site locations with corresponding δD_{SMOW} values.

5,280 ft. and 6,070 ft., and have δD values of -107‰ and -129‰, respectively. Despite having only three samples, a depletion in the δD values with increasing elevation is evident. The low elevation rain sample probably underwent fractionation during falling resulting in the heavy δD signature. Based on the δD of the snow samples, it seems likely that recharge waters from higher elevations will have an even lighter isotopic signature than the -129‰ value of sample RC91SN2.

A distinct isotopic signature difference exists for waters entering the ground at different elevations. Table VI shows δD depletions in precipitation with increasing elevation in the Sierra Nevada Mountains based on a study by Friedman and Smith (1970).

TABLE VI

CHANGES IN δD OF PRECIPITATION WITH INCREASING ELEVATION IN THE SIERRA NEVADA MOUNTAINS

Elevation (ft)	δD_{SMOW}‰
8,000-9,000	-146.5
7,000-8,000	-136.5
6,000-7,000	-126.5

If a 10‰ depletion for every 1,000 ft. increase in elevation holds true for Kelly Creek Basin, the lightest recharging waters should have a δD of about -145‰. Of course, with the elevation increase, there is a corresponding surface area decrease. Therefore, the amount of recharge with a signature as light as -145‰ is small. Mixing of these waters with recharge from lower elevations should produce the isotopic compositions of springs and basinal ground waters.

Surface Water

All surface water samples collected within Kelly Creek Basin are from streams. The ephemeral nature of the drainages resulted in most samples being taken in early summer while spring runoff was still supplying water. The stream δD values ranged from -108‰ to -121‰ with a general enrichment occurring in a mid-basin direction. Chimney Reservoir, five miles to the north of the basin divide, represents the only perennial surface water in the area; its δD value of -85‰ reflects non-equilibrium fractionation in this dry, high temperature environment. Refer to Table VII for δD values and elevations of all surface water samples.

Streams are generally gaining in the mountains of Kelly Creek Basin, resulting in depleted ground waters contributing to the isotopic composition. The ground water is derived from snowmelt at higher elevations where isotope signatures are lighter. If ground water input to the stream is somewhat constant, isotopic compositions stay at consistent values. However, away from the range fronts, all streams in the basin become losing, and evaporation plays the major role in altering the isotopic signature of the water. Larger drainages usually show less of an isotope shift from evaporation than small drainages.

Three stream samples were taken along Kelly Creek. At all locations the stream was flowing on basin-fill alluvium. Sample site RC91ST1, at 5,167 ft., is the most up gradient, and has the most depleted δD at -120‰. Sample RC91ST4 was taken approximately 8 miles downstream from RC91ST1, and had a δD=-119‰. Six miles farther downstream sample RC91ST3 was obtained at 4,511 ft. and had a δD=-118‰. The slight enrichment of the stream water in a down gradient direction is probably a result of evaporation. As the lighter isotopes preferentially go into the vapor phase due to evaporation, heavier water is formed. However, given the precision of ± 1‰ for deuterium analyses and the discrepancies in sampling times, these variations could lack significance.

TABLE VII

SURFACE WATER ISOTOPE DATA

Sample	δD_{SMOW}‰	Elevation (ft)	Location
RC91ST1	-120	5,167	Kelly Creek
RC91ST2	-108	4,954	Jake Creek
RC91ST3	-118	4,511	Kelly Creek
RC91ST4	-119	4,675	Kelly Creek
RC91ST5	-119	5,577	Osgood Creek
RC91ST6	-118	6,398	Osgood Creek
RC91ST7	-121	5,905	Julian Creek
RC91ST8	-113	4,921	Osgood Creek
RC91ST9	-117	6,234	Summer Camp Cr.
RC91RV	-85	4,593	Chimney Reservoir

Osgood Creek, like Kelly Creek, was sampled at three locations. In a down gradient direction, its δD values are -118‰, -119‰, and -113‰ for sample sites RC91ST6, RC91ST5, and RC91ST8, respectively. Sample sites RC91ST6 and RC91ST5 are located one mile apart, and are both within the mountains. The slight depletion that has occurred could be due to light signature springs discharging into the creek below sample site RC91ST6. However, the 1‰ difference is within the $\pm$1‰ precision for the analytical technique. By sample site RC91ST8, a significant reduction in flow had occurred and δD rose to -113‰. Within 1.5 miles from sample site RC91ST5, a 6‰ enrichment had taken place. This is considerably more than the 2‰ enrichment that occurred over a 15 mile stretch along Kelly Creek. The size difference between the two creeks appears to be the main reason for this phenomenon. Kelly Creek is 7-10 ft. wide with water depths of 1+ ft., while Osgood Creek is closer to 2 ft. wide with less than 4 inches of depth in most places. Another consideration is that most of the fractionation of Osgood Creek water occurs away from the mountain front. Vegetation cover in the Osgood Creek canyon could be playing a role in lessening fractionation in the upper reaches of the drainage. The loss of trees and shade between RC91ST5 and RC91ST8 allows for higher temperatures and probably contributes to the increased fractionation. The lack of trees along Kelly Creek does not effect the isotopic composition because a significant part of its discharge seemingly results from ground water inflow within this reach of the drainage.

The lightest stream water in the basin came from the headwaters of Julian Creek (RC91ST7). The sample was taken at 5,905 ft., and had a δD=-121‰. Flow in the drainage was swift, but within 1.5 miles of the sample site, all water had infiltrated and/or evaporated. Turbulence associated with the steep gradient conditions lends itself to greater fractionation, but in this environment, the lower temperatures and vegetation cover at higher elevations play a more important role in reducing evaporative fractionation.

Samples RC91ST9 and RC91ST6 were taken at 6,234 ft. and 6,398 ft., respectively. Although sampled at higher elevations, both were taken along moderate gradient stretches with limited shielding from vegetation. This could enable greater evaporation along these parts of the drainages, and create the enriched δD values. Summer Camp Creek (sample RC91ST9) had minor flow and a δD=-117‰, while Osgood Creek (sample RC91ST6) had a δD=-118‰.

Sample sites RC91ST2 and RC91RV are the most enriched surface water samples taken from the basinal region. The δD=-85 for sample site RC91RV indicates that the standing water in this environment is subjected to significant enrichment from evaporation under non-equilibrium conditions. This is also shown in Figure 23, which illustrates that Kelly Creek Basin waters plot on the -d parameter side of the LMWL and the MWL. Sample site RC91ST2 is located along a low to moderate gradient stretch of Jake Creek with no vegetation and has a δD=-108‰. The larger size of Jake Creek (5-10 ft. wide and approximately 1 ft. deep) should enable it to maintain more of its recharge isotopic signature. However, the fact that it flows directly on basaltic bedrock is apparently affecting its isotopic composition: the dark color of the basalt may cause higher temperatures, thereby leading to increased evaporation and isotopic fractionation.

Ground Water

Twenty-four ground water samples, consisting of 10 springs (designated by 'SP' suffix), eight wells, and six drill holes, were taken in Kelly Creek Basin. Isotopic compositions are generally lighter than those of surface water samples, owing to less evaporation to the atmosphere.

Springs in the vicinity of stream samples tend to have similar, but slightly depleted δD values. The lightest ground waters come from deep wells and drill holes in mid-basin with $\delta^{18}O$=-17.4‰ and δD=-136‰, while the most enriched come from short flow path springs with $\delta^{18}O$=-15.4 and δD=-118‰ (Figure 21, Table VIII).

TABLE VIII

GROUND WATER STABLE ISOTOPE DATA

Sample	δD_{SMOW}‰	$\delta^{18}O_{SMOW}$‰
BAC-4	-123	-17.4
BAC-5	-125	
BAC-6	-136	
BAC-8	-120	
BAC-9	-122	
DE-6	-127	-15.4
DE-36	-133	
MURD-5	-126	-16.3
OW1	-130	
OW4 (150')	-128	
OW4 (300')	-128	
RC91SP1	-122	-15.6
RC91SP2	-124	
RC91SP3	-125	-15.1
RC91SP4	-126	
RC91SP5	-120	
RC91SP6	-118	-15.4
RC91SP7	-118	
RC91SP8	-123	
RC91SP9	-123	
RC91SP10	-127	-16.1
SEE-161	-136	-17.0
SEE-630	-128	
SEE-647	-128	-16.3
91-124	-130	-16.1

Springs from the Snowstorm Mountains have δD values that range from -122‰ to -126‰ and $\delta^{18}O$ values that range from -15.1‰ to -15.6‰. Sample sites RC91SP1 and RC91SP2 are located adjacent to Kelly Creek at 5,627 ft. and 5,577 ft., respectively. A snow core approximately 500 ft. up slope from site RC91SP1 had a δD=-129‰, yet the spring had a δD=-122‰. The difference in values could result from fractionation of shallow subsurface flow between the recharge area(s) and the spring. Another possibility could be fractionation during sampling because of the time expenditure required for sampling minimal discharge springs. Sample sites RC91SP3 and RC91SP4 are the two lowest elevation springs sampled in the basin at 5,413 ft. and 5,167 ft., respectively; however, their δD values of -124‰ and -125‰ are two of the most depleted. Perhaps the low elevation discharge point represents deeper flow path water from higher elevation recharge.

Osgood Mountain springs are all at higher elevations than those sampled in the Snowstorm Mountains. The two springs sampled in close proximity to stream drainages have isotopic signatures markedly similar to the stream water. Sample sites RC91SP6 and RC91SP7 were obtained within 400 ft. of sample sites RC91ST6 and RC91ST9, respectively. In neither location, however, was the spring water the source of the stream water. Sample RC91SP6 was taken adjacent to stream sample RC91ST6 and both δD values are -118‰. A similar source for both waters appears likely. The fact that the ground water and surface water have such comparable signatures could mean one of two things: 1.) that sufficient ground water is replenishing the stream to minimize the rates of evaporative fractionation, or 2.) evaporative fractionation is affecting both waters at the same rate. The latter hypothesis would indicate very shallow flow paths for water emanating from the spring. A close proximity to the surface would allow similar evaporative fractionation effects to exist for the spring and the stream. Sample site RC91SP7 is down gradient from stream sample RC91ST9. The spring is depleted by only 1‰ relative to the stream. The stream is likely infiltrating and mixing with ground water causing a δD enrichment in the spring water. Since the spring discharges at 6,152 ft., a δD value more depleted than -118‰ would be expected based on Table VI.

Sample site RC91SP5 is located within a stream drainage of fairly steep gradient. The steplike nature of the stream creates abundant turbulation of the water as it travels down slope. At the sampling area there are a series of springs, and the orifice of any one is difficult to pinpoint. The water seems to infiltrate and discharge repeatedly along the course of flow. Highly permeable gravel from weathered granodiorite enable this situation. Delta D values of -120‰ probably result from fractionation due to water turbulation. The water could potentially be even more enriched but abundant vegetation cover has a regulating effect on temperature and evaporation.

Sample sites RC91SP8 and RC91SP9 are located approximately 600 ft. away from each other, and have less than 100 ft. of vertical elevation change between them. They were sampled to test if springs in close proximity to one another maintain similar flow paths, and hence, similar isotopic compositions. In this case, similar flow and mixing histories appear likely since both springs have δD=-123‰.

The northernmost Osgood Mountain spring sample, RC91SP10, had the lightest δD at -128‰. A pipe exiting the ground with a match stick trickle of water represented the sampling location. A high elevation recharge must be contributing to this spring since it is one of the lightest waters within the basin. Isotopically similar waters are present in wells from mid-basin, but seemingly result from longer travel along deeper flow paths. If sample RC91SP10 is of a comparable age to deep mid-basin waters and has a subsurface flow pattern representative of deep mid-basin waters, a structural conduit originating at depth must be providing the path that enables discharge at this higher elevation.

Wells and drill holes show isotopic changes in δD that reflect the depth of the hole (Figure 22). Holes that penetrate to greater depths have consistently lighter isotopic signatures than shallower holes. Deep flow paths apparently contain more high elevation recharge that is not affected by mixing with enriched shallower water systems.

Sample sites BAC-4, BAC-5, BAC-8, BAC-9, and MURD-5 are all shallow ranch wells and all have δD values between -120‰ and -126‰. Site BAC-4 is within 30 ft. of Kelly Creek and has δD=-123‰. Permeable gravel provides hydrologic communication between the creek and the ground water, with the elevation of the well water and the stream stage being the same. A 3‰ δD enrichment of the creek water relative to the ground water signifies less evaporative fractionation of shallow ground water than of Kelly Creek water.

At ranch well BAC-8, next to Jake Creek, stream water is recharging the alluvium creating δD=-120‰. Jake Creek is a gaining stream upgradient from the well meaning that ground water and fractionated surface water contribute to the isotopic signature of well BAC-8. The depth of the well is not sufficient to reach deeper flow paths from higher elevation recharge zones. This scenario also holds true for site BAC-9 with δD=-122‰. The δD value is very close to the δD=-121‰ from a stream sample in Julian Creek that was taken up gradient. The fractionated creek water mixing with lower elevation recharge make up the isotopic composition of site BAC-9 well water.

Sample site MURD-5, and to a lesser extent site BAC-5, tap water in permeable gravel within alluvial fan deposits of weathered Osgood Mountains material. At site MURD-5 the well is supposedly drilled to 500 ft. and is screened at various intervals. Water is therefore a mixture of various elevation recharge zones as well as a mixture of different aged waters. This explains the relatively enriched nature of the sample with (δD=-126‰) compared to the other well in the basin that has a depth exceeding 500 ft. (BAC-6). Well BAC-5 penetrates only 60 ft. of alluvium and extracts water from much finer grained material than site MURD-5. Its location adjacent to, and subsequent influence from Kelly Creek (within 600 ft.) contributes to the isotopic signature of δD=-125‰. Enriched stream water is infiltrating and mixing with ground water of lighter isotopic composition.

Most of the remaining sites are located in the vicinity of the Rabbit Creek and Chimney Creek gold deposits of Santa Fe Pacific Mining, Inc. and Gold Field's Mining, respectively. Within an eight site cluster, SEE-161 had the most depleted δD and $\delta^{18}O$ at -136‰ and -17.0‰, respectively. Sample locations are all unpurged observation wells or drill holes, making fractionation a viable problem. To account for this, samples were taken at least 50 ft. below the water-level surface whenever possible. Sampling from these depths greatly minimizes atmospheric fractionation.

At sites SEE-630 and SEE-647 the drill holes collapsed less than 25 ft. from the top of the water column. Samples obtained had a δD=-128‰, and fractionation could not be discounted. However, at observation well OW4, two samples were taken at different depths to test fractionation vertically down the water column. One sample was taken at 80 ft. below the water table and the other was taken 230 ft. below the water table. The δD values of both were -128‰. The lack of change in δD down the well bore is a good indication that significant depths to water mitigate the effects of evaporative fractionation.

Sites SEE-630, SEE-647, and OW4, as well as DE-6 (δD=-127‰), are all located very close to stream drainages. The extreme depths to water and dry climate hinder water movement through the unsaturated zone in its attempt to reach the water table. It is possible that some isotopically enriched infiltration from stream runoff is making its way down and mixing with ground water. The likeliness of that happening, however, is low, unless there was rapid recharge from water movement directly down a bore hole or a fracture. Drill holes penetrate zones of differing isotopic signatures based on depths; greater depths usually result in more depleted δD values (Figure 22). Depending on which zones are breached, mixing will result in changing the drill hole water isotopic composition. The lightest signatures will undoubtedly come from the holes penetrating the deepest flow systems. Mixing within a bore hole could produce the slight scatter in δD values within this area.

Depth to water is playing a role in establishing the isotopic signature of basinal waters. Figure 22 illustrates that with increasing depth to water in drill holes and wells within the basin-fill alluvium, δD becomes more and more depleted. Sample sites DE-6 and MURD-5 are the only sites to show deviation from this pattern. Site DE-6 has likely undergone evaporative fractionation, while site MURD-5 is screened at

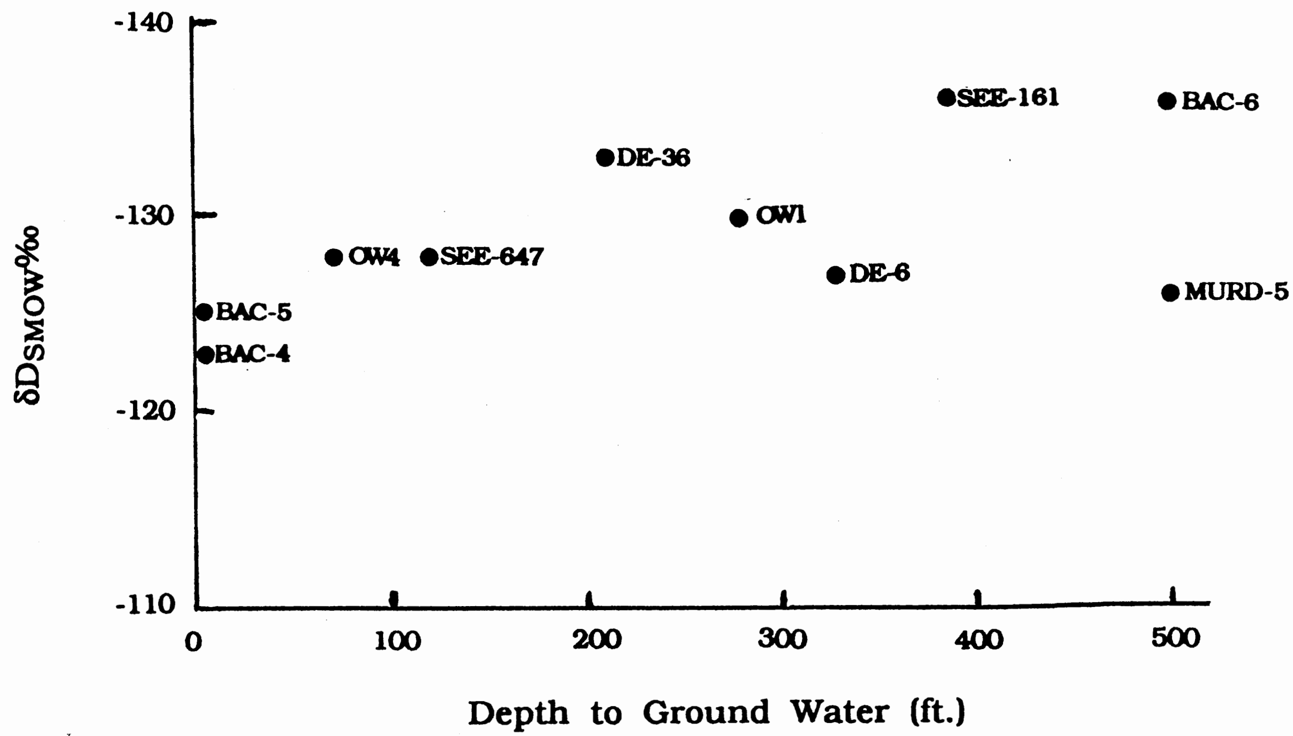


Figure 22. δD vs. depth to water plot of wells and drill holes within the basin-fill alluvium.

various depths which represents a mixture of zones with differing isotope compositions.

Sites SEE-161, OW1, DE-36, 91-124, and DE-6 are the only samples from the mining area with a predominant ground-water flow component coming from the western side of the basin. If sample DE-6 is discounted, they also represent the lightest δD values at -136‰, 130‰, -133‰, and -130‰, respectively. Since three of these are exploration drill holes, and the mineralized target depth for each is probably similar, it is possible that they are all penetrating zones of comparable depths.

The most down gradient sample in the study area came from site BAC-6 at Hot Springs Ranch. The well tapped a confined aquifer at a depth exceeding 500 ft. Within the ranch boundary are numerous small hot springs, although none were flowing during the sampling times of this project. The relationship of these springs to the hydrology of the basin is not known, but they must originate at considerable depth. The artesian water δD=-136‰. The recharge for a water of this isotopic signature in a present-day climate must come from above 7,000 ft. in the surrounding mountains. A comparison of the sample location to the flow net in Figure 13 indicates a dominant water supply from the east. This indicates a very long and deep flow path with an origin in the Snowstorm Mountains.

Deep samples from mid-valley are the most depleted in the Kelly Creek Basin. Flow systems originating at high elevations appear to be supplying water to deep-seated confined aquifers. However, given the length of time (in some cases millennia) it can take for water to travel from recharge areas to discharge areas in this environment, it is possible that the more depleted, deep alluvial aquifers contain water that infiltrated at a time period when climatic conditions were different than at present. Springs within the mountains represent short flow path ground water dominated by lower elevation recharge. The length of time for spring water subsurface travel does not appear to indicate different climatic conditions existed at the time of their recharge. Spring water isotopic compositions are also affected by mixing with streams and/or evaporative fractionation.

δD-$\delta^{18}O$ Plot

Climatic conditions in northern Nevada warrant the use of a LMWL. Jacobson and others (1983) developed a LMWL based on 34 snow cores and eight rain samples from Dixie Valley, approximately 100 miles SSW of Kelly Creek Basin. Their LMWL, and the MWL of Craig (1961) are shown in Figure 23 in relation to Kelly Creek Basin water samples. The MWL and LMWL are:

$$\delta D = 5.8\delta^{18}O - 25 \quad \text{(LMWL)}$$

$$\delta D = 8\delta^{18}O + 10 \quad \text{(MWL)}$$

All Kelly Creek samples analyzed for $\delta^{18}O$ and δD plot on the -d-parameter side of the LMWL and the MWL. This indicates that evaporation under non-equilibrium conditions at elevated temperatures produced these isotopic signatures. The data appears to trend parallel to the MWL. It could be that sample sites SEE-161 and RC91ST8 bias the cluster, or that there exists a mixing/evaporation trend. Samples with more depleted δD values are deep basinal waters. It is not believed that these samples have undergone significant, if any, enrichment due to evaporation. The most enriched sample was obtained from a stream. This

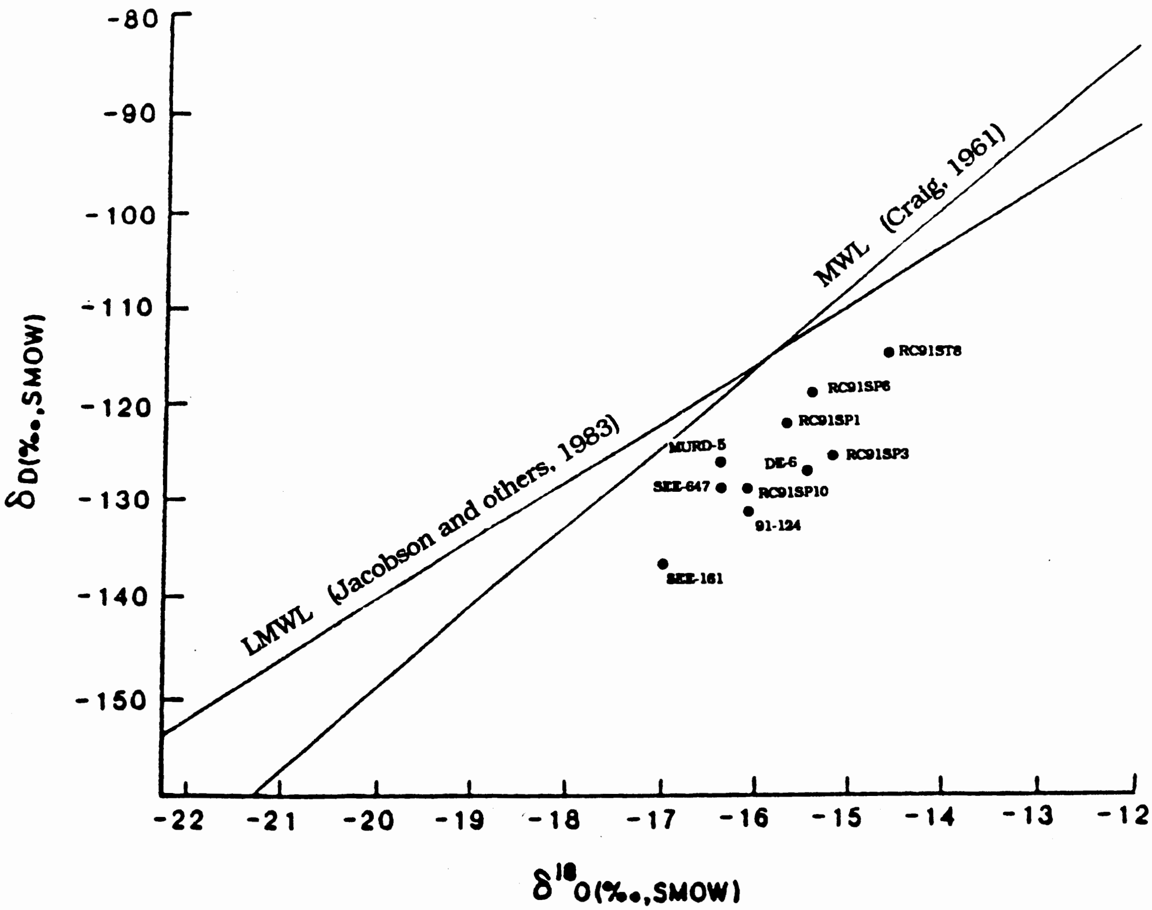


Figure 23. δD vs. $\delta^{18}O$ plot showing Kelly Creek Basin waters in relation to the global MWL and a LMWL.

sample has undoubtedly undergone some degree of evaporative fractionation. It is possible that the springs and shallower wells represent mixing between the relatively depleted deep basinal waters and the relatively enriched surface water. A mixing line could be drawn between site RC91ST8 and site SEE-161. It seems that the isotopic composition of waters within the Kelly Creek Basin are affected by a combination of mixing and evaporative fractionation.

Tritium

Tritium samples were analyzed from three sites within the Kelly Creek Basin. Sample RC91SP8, in the Osgood Mountains, registered the highest level of tritium at 30 TU. The lowest level of 1 TU was obtained from site 91-124 in the northern part of the mid-valley region. Sample RC91SP3, from a low elevation spring in the Snowstorm Mountains, had TU=2.

The high tritium content in the waters of site RC91SP8 results from a short residence time in the subsurface. The relatively high elevation at the sampling site of 6,398 ft. indicates that the water probably did not travel a great distance between recharge and discharge. Recharge could not have occurred above 7,000 ft. because δD=-123‰ (Table VI). The fact that deuterium is enriched and tritium is high signals a short residence time for a ground water that was recharged at relatively low elevations.

Sample RC91SP3 was taken at an elevation of 5,313 ft. The low elevation discharge point, and a δD=-125‰ provide the possibility of a longer residence time in the subsurface. The TU value of 2 indicates a ground water that is older than the transient nature of tritium.

Site 91-124 is a borehole in the valley that penetrates bedrock underlying the basin-fill alluvium. Its low δD (-130‰) and $\delta^{18}O$ (-16.1‰) indicate recharge from high elevations in the adjacent mountains or recharge under different climatic conditions. A long flow path and hence, long residence time, lead to a TU=1.

Waters with long residence times (>100 years) have low tritium concentrations. Basin and range hydrologic systems typically take hundreds or thousands of years for water to travel from recharge areas to discharge areas. Within this time period, infiltrated bomb induced tritiated precipitation will decay. Therefore, unless samples are taken along a short flow path, commonly a high elevation spring, tritium's usefulness in this type of environment is limited.

Radiogenic Isotopes

Lead

Lead signatures of water samples are variable within Kelly Creek Basin. A tendency towards more radiogenic ratios exists in a N-NE direction. Values of $^{206}Pb/^{204}Pb$ range from 18.632 to 20.090. Highest ratios probably reflect interaction with limestone and/or old igneous or metamorphic units, while lower numbers are probably related to young igneous sources or atmospheric deposition. Young igneous rocks in this region have $^{206}Pb/^{204}Pb$ ratios that range between 19.0 and 19.5, while U.S. aeolian $^{206}Pb/^{204}Pb$ ratios are commonly less than 19.0 (T. Bullen, 1990). Lead sample localities are shown in Figure 24.

The sample cluster in the north-central part of the basin has particularly high lead isotopic ratios. Exploration wells and drill holes penetrate altered volcanics and metasedimentary rocks beneath the valley

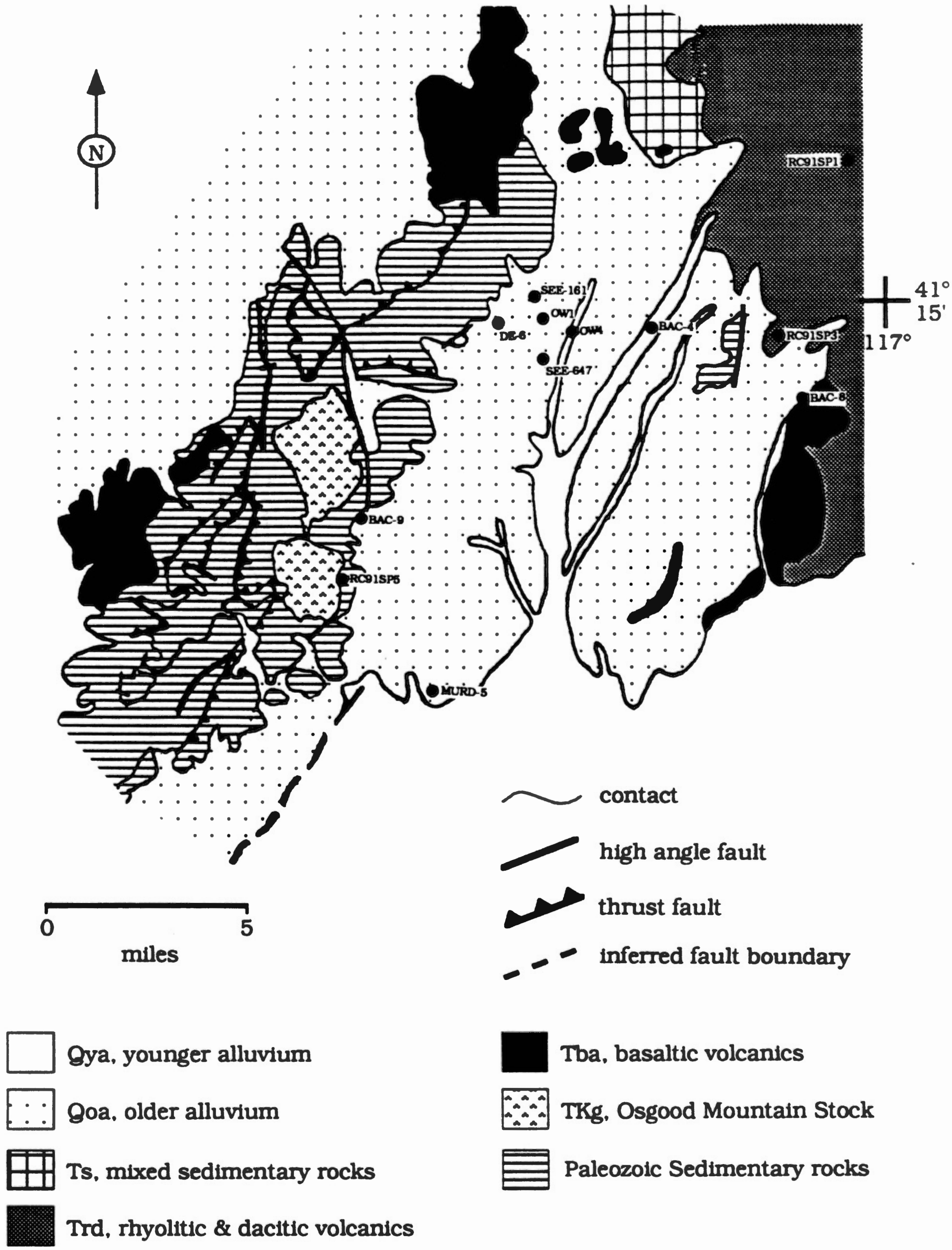


Figure 24. Lead isotope sample locations as related to Kelly Creek Basin geology.

fill. Paleozoic limestone units are believed responsible for the elevated $^{206}Pb/^{204}Pb$ ratios of 20.090 and 20.043 in drill holes SEE-161 and SEE-647, respectively. The Etchart Limestone is present in the vicinity of site SEE-161, and altered or silicified limestone is believed to have been penetrated in borehole SEE-647.

Observation wells OW1 and OW4 have slightly lower ratios than SEE boreholes. Interestingly, the observation wells do not achieve the depths of the drill holes, and their lead signatures are less radiogenic. They are not influenced as much by the Paleozoic limestone because they are primarily in contact with valley-fill alluvium. The 19.588 value of OW4 is an average of two samples. The first sample was taken at a depth of 150 ft. (80 ft. below water table), and the second sample was taken at a depth of 300 ft. (230 ft. below water table). The $^{206}Pb/^{204}Pb$ ratios for each depth are 19.382 and 19.793, respectively. The vertical increase in the ratio down the well reflects proximity to the higher $^{206}Pb/^{204}Pb$ limestone within the underlying bedrock. The shallower water sample, influenced more by the valley-fill alluvium, contained a significantly lower lead $^{206}Pb/^{204}Pb$ ratio.

Site OW1 is used to monitor drawdown next to the Rabbit Creek pit. The $^{206}Pb/^{204}Pb$ ratio of 19.614 indicates a mixture of shallow, alluvium derived lead, with deeper, limestone influenced lead. This results from dewatering activities at the mine. Despite the observation well being deep and in contact with more radiogenic lead in the bedrock, induced flow consisting of less radiogenic lead from contact with the alluvium is being drawn towards the cone of depression surrounding the pit.

Site DE-6 is located west of the previous samples on the rising slope of the Dry Hills. The $^{206}Pb/^{204}Pb$ ratio of 19.814 indicates that the water is in contact with old uranium-rich bedrock, again believed to be Paleozoic limestone units, possibly the Etchart Limestone. The reason that the Etchart Limestone is believed to influence the lead ratio of many of the drill holes is that it hosts mineralization within the Chimney Creek deposit of Gold Field's Mining. Therefore, it would seem to be a target unit during many drilling operations in the northern part of the basin.

Samples from the south and southwest part of the study area contain less radiogenic lead. Their proximity to the Osgood Mountain Stock could be a factor. Site RC91SP5 is located on the contact between the granodiorite stock to the west, and Paleozoic sedimentary rocks to the east. The stock is up gradient and presumably represents the host within which the spring water had been travelling. The $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios, 19.034 and 38.636, respectively, are considerably lower than the ratios of the five samples collected near the mining area.

Sites BAC-9 and MURD-5 are ranch wells from the area near site RC91SP5. Site BAC-9 is a relatively shallow well on the rising eastern face of the Osgood Mountains. The Preble Formation, which crops out to the west, consists of shale and quartzite with minor limestone. Farther up gradient is the granodiorite stock. The $^{206}Pb/^{204}Pb$ ratio of 19.321 for BAC-9 may reflect flow through both rock suites. Site MURD-5 taps water flowing through granodiorite-derived gravel within the valley-fill alluvium. $^{206}Pb/^{204}Pb$ of 18.905 could reflect the Cretaceous granodiorite, or may be influenced by atmospheric lead signatures in the alluvium. These commonly range between 18.6 and 18.8, but it can vary depending on local sources.

The remaining sample sites are all located on the eastern side of the basin. Three are in the Snowstorm Mountains, and one is two miles east of the Rabbit Creek deposit adjacent to Kelly Creek. Sample site RC91SP1 is a spring in Kelly Creek canyon located at approximately 5,577 ft. It has $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ lead ratios of 19.860 and 39.083, respectively. Erosional windows of Paleozoic sedimentary packages are known to exist in the Snowstorm Mountains, but the only rock types mapped in the vicinity of the sampling site are Tertiary rhyolitic and dacitic volcanics. These units would not be expected to be quite so radiogenic. The spring water must have picked up the more radiogenic signature during subsurface contact with a uranium rich source rock. Delta D and $\delta^{18}O$, however, are not significantly depleted to indicate a high elevation recharge area, and hence, a deeper flow path. Therefore, the lead signature of the water must have been obtained from contact with rocks of shallow depth located relatively close to the sampling location.

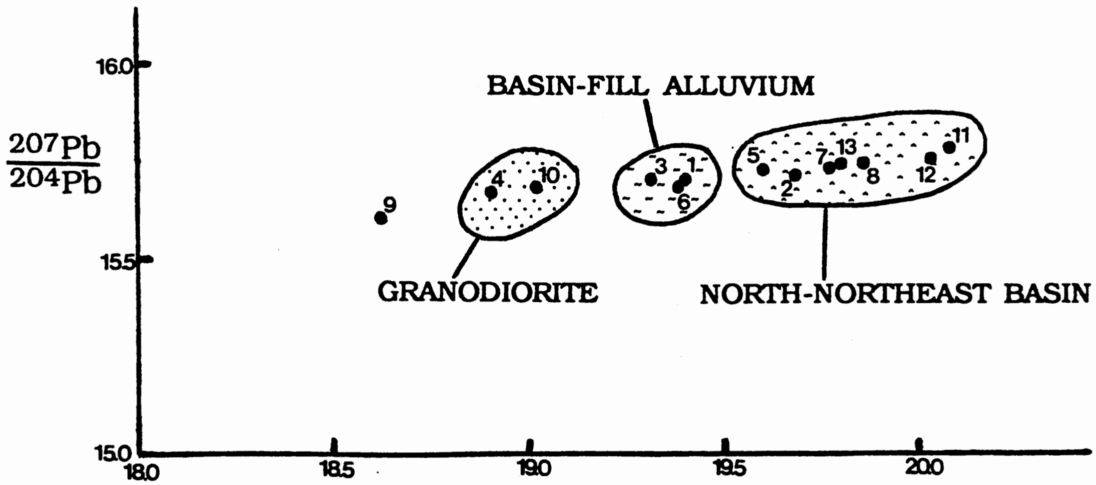
Site BAC-8 has a $^{206}Pb/^{204}Pb$ ratio of 19.689. It is a ranch well that taps water from the floodplain of Jake Creek. The high ratio is not typical of a water in contact with Tertiary rhyolitic and basaltic rock derived alluvium. Something is elevating the ratio compared to the 19.0 to 19.5 values expected from most igneous rocks. Contact with sedimentary units is possible, but the drainage basin of Jake Creek is too large to enable confirmation. It should be noted, however, that Valmy Formation outcrops of chert and siliceous shale are present in this area, and could be elevating the lead signature of the water.

The lowest lead isotopic ratios are from site RC91SP3. This spring, on the western face of the Snowstorm Mountains, has $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ values of 18.632 and 38.330, respectively. Atmospheric lead trapped on the mountain face by westerly winds is believed to be, at least in part, responsible. However, Valmy Formation crops out within 100 ft. of the spring which would seemingly elevate the lead isotopic ratios.

Overall, the lead isotopic ratios of the Snowstorm Mountains are not easy to explain. But, the ratios appear to indicate that ground water is coming in contact with deeper, older rocks. The young volcanic rocks are likely covering rocks that have a more radiogenic lead signature. This indicates that the lead isotopic ratio of ground water is not being influenced to a large degree by the Tertiary volcanics. This could result from relatively rapid flow through the volcanics and longer residence times in the underlying older rocks.

Site BAC-4 is a livestock well next to Kelly Creek. It contains a lead signature ($^{206}Pb/^{204}Pb=19.404$) that appears to reflect a mixture of high ratio waters from the Snowstorm Mountains and lower ratio waters in contact with valley-fill alluvium. Depth to ground water is very shallow (<10 ft.) because of the well's proximity to Kelly Creek. Shallow water depths allow greater contact with alluvium. Alluvium composition at this site is indicative of rocks from both ranges. It is in many ways similar to OW4 (150'); the alluvial composition consists of a fairly even mixture of high and low ratio material which acts to produce an 'intermediate' lead isotopic ratio.

Table IX lists lead ratios and sample numbers used in the construction of Figure 25. From these plots it is evident that samples with more radiogenic lead (higher lead ratios) come from the Snowstorm Mountains and the mining area. Numbers 2,5,7,8,11,12, and 13 are all in the north and northeast region of the basin, and all plot in the higher



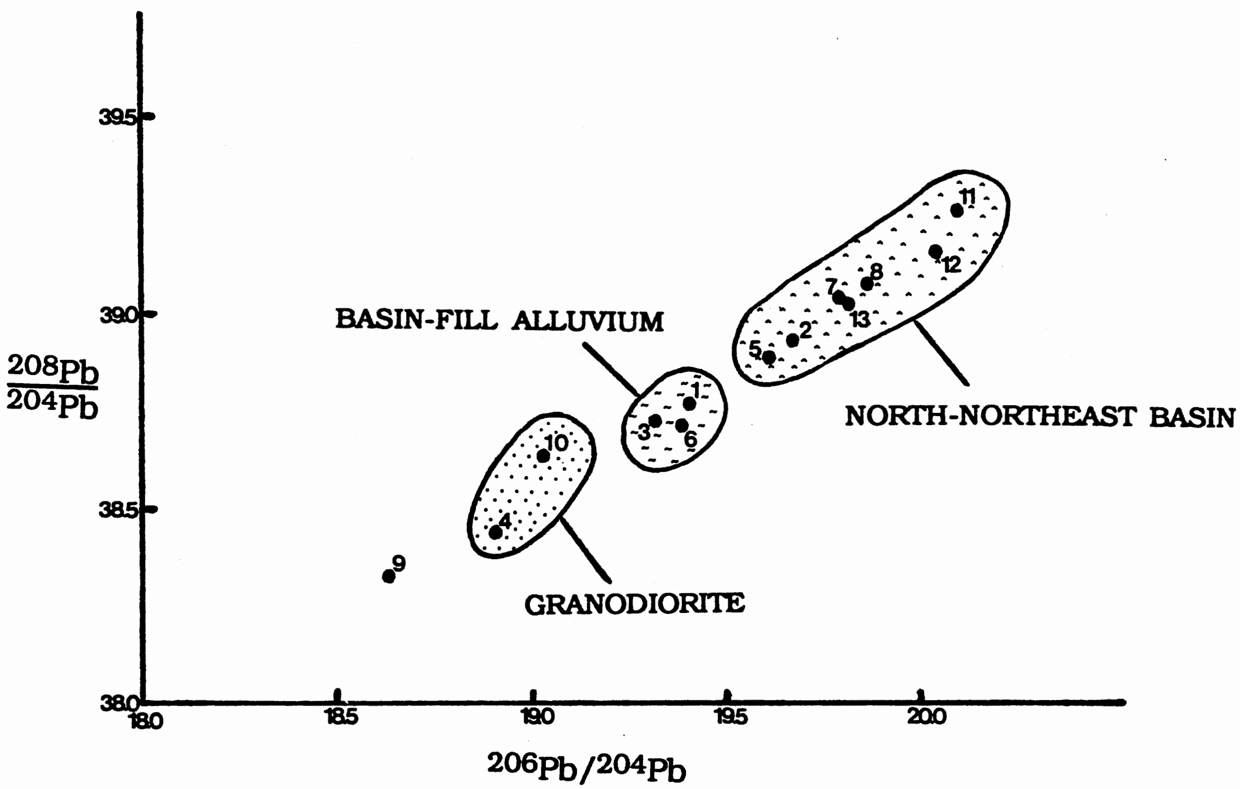


Figure 25. Plot of $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$.

ratio, or more radiogenic direction on the graphs (Figure 25). Samples in the valley-fill alluvium are affected by the rock compositions from each of the bordering ranges. This results in numbers 1,3, and 6 plotting in the middle of the data cluster. Numbers 4 and 10 are likely influenced by

TABLE IX

LEAD RATIOS FROM KELLY CREEK BASIN

Number	Sample	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
1	BAC-4	19.404	15.707	38.769
2	BAC-8	19.689	15.720	38.936
3	BAC-9	19.321	15.704	38.726
4	MURD-5	18.905	15.656	38.446
5	OW1	19.614	15.728	38.886
6	OW4 (150')	19.382	15.686	38.720
7	OW4 (300')	19.793	15.740	39.048
8	RC91SP1	19.860	15.746	39.083
9	RC91SP3	18.632	15.610	38.330
10	RC91SP5	19.034	15.680	38.636
11	SEE-161	20.090	15.781	39.257
12	SEE-647	20.043	15.759	39.153
13	DE-6	19.814	15.746	39.027

the granodiorite, and lie at the lower ratio end of the plots. Number 9 is the only sample that does not follow the N-NE trending radiogenic increase pattern. A possible explanation is that the influence of atmospheric lead has caused it to plot as the least radiogenic sample despite coming from the northeast part of the basin.

The data clusters on Figure 25 could be interpreted as mixing arrays. The most radiogenic waters are influenced by Paleozoic limestone units, and the least radiogenic waters (discounting number 9) are influenced most by the granodiorite. Alluvium derived from both, or water that has been in contact with both, plots in between.

Strontium

As with the lead, changes in geology dictate fluctuations in $^{87}Sr/^{86}Sr$ ratios in waters of Kelly Creek Basin (Figure 26). Paleozoic sedimentary rocks produce waters with $^{87}Sr/^{86}Sr$ values that are greater than 0.710, while rhyolite, basalt and granodiorite are generally 0.708 or less. The water signatures are more representative of particular rock types in the mountains than in the valley-fill alluvium. The valley-fill contains weathered material from all lithologies, and hence, has intermediate ratios.

The highest and lowest $^{87}Sr/^{86}Sr$ ratios come from the Osgood Mountains. Site BAC-9 is a relatively shallow well that penetrates the Preble Formation, and possibly the Comus Formation, on the eastern face of the range. The Preble Formation is an interbedded limestone and shale with a few quartzite beds, while the Comus Formation is an alternating sequence of dolomite, limestone, and shale. These rocks produce waters with the highest $^{87}Sr/^{86}Sr$ ratios of any in the basin at 0.7123. In close proximity to site BAC-9, spring sample RC91SP6 exits the ground just down gradient from the Preble Formation in Osgood Creek canyon. Its $^{87}Sr/^{86}Sr$ ratio is 0.7113. The Preble Formation is undoubtedly playing a role in elevating the $^{87}Sr/^{86}Sr$ signature of waters that come into contact with it.

Sites RC91SP5 and RC91SP8 are springs located within two miles to the south and north of the previously mentioned samples. They both

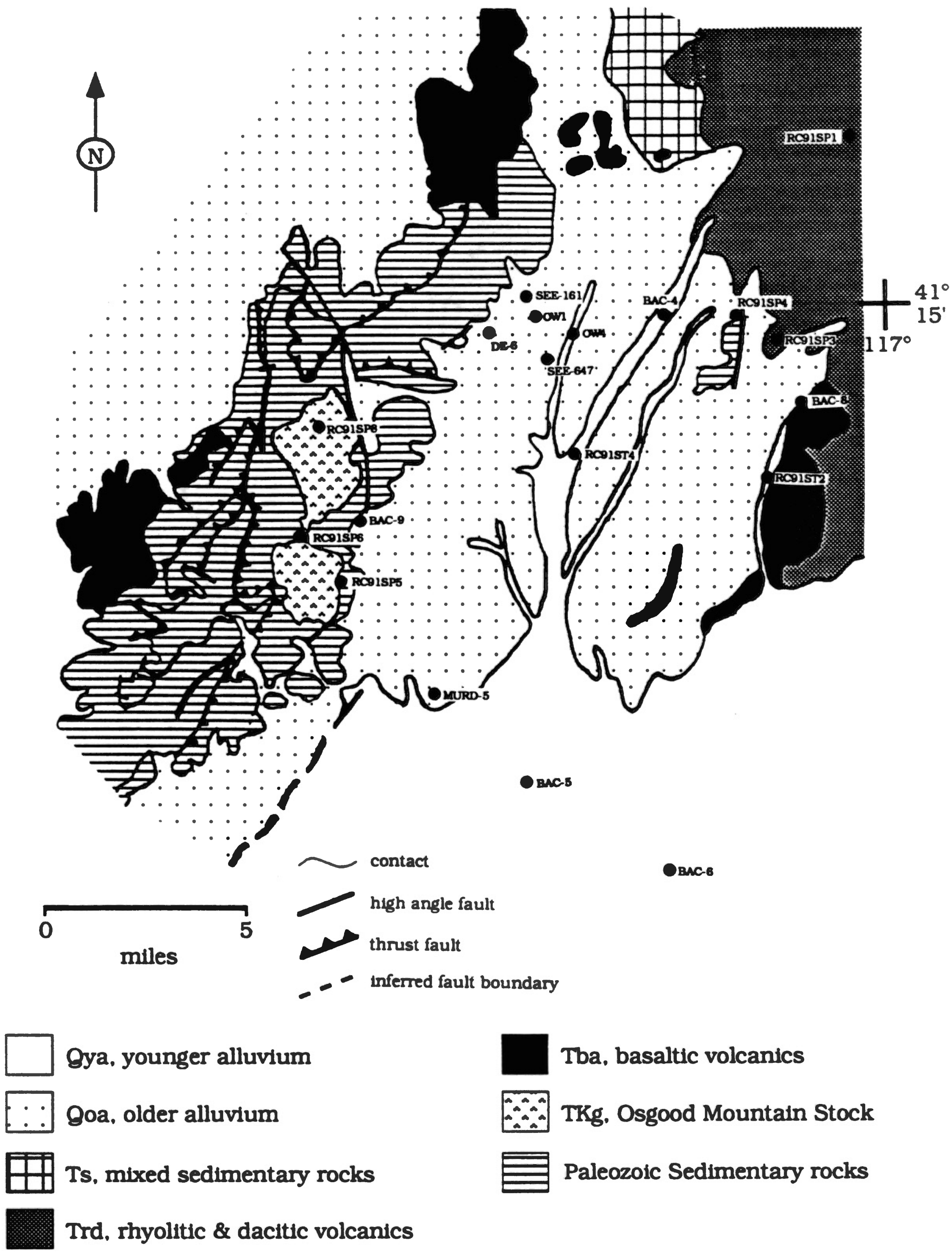


Figure 26. Strontium isotope sample locations as related to Kelly Creek Basin geology.

represent waters flowing through fractures in the Osgood Mountain Stock. The stock is a relatively young (TK) granodiorite body locally cut by aplite dikes. The 0.7077 and 0.7071 strontium ratios are distinctly lower than the nearby Preble Formation waters.

Six samples were obtained from the mining area in the north-central part of the basin. Strontium signatures range between 0.7084 and 0.7098. The lowest ratio is from site DE-6 near the Dry Hills. Its value represents a significant influence from the valley-fill alluvium in acquiring the low $^{87}Sr/^{86}Sr$ signature. Perhaps the borehole does not achieve the depths to enable contact with Paleozoic sedimentary rocks, or drill hole collapse has hindered good hydrologic communication with the underlying bedrock.

Sites SEE-161, SEE-647, and OW1 have $^{87}Sr/^{86}Sr$ ratios of 0.7098, 0.7096, and 0.7096, respectively. The fact that all of these values are close, and all of the sites are within a mile and a half of one another, indicates that similar units are affecting the waters in each of the boreholes. The alluvial influence that appeared in site DE-6 is not as strong in these holes. Their greater depth allows for more of an influence from Paleozoic sedimentary rocks. As with lead samples, these ratios are likely affected by limestone units.

Observation well OW4 was sampled at two different depths below the water table. Lead ratios showed a noticeable change to higher values with increasing depth. This seems to indicate that proximity to bedrock was accompanied by a more radiogenic isotopic signature in the ground water. The strontium ratios at the two depths, however, were identical at 0.7089. The $^{87}Sr/^{86}Sr$ signature difference between the bedrock and the basin-fill alluvium must not be significant enough at this location to allow vertical compositional changes within the well.

Sites RC91SP1, BAC-4, AND RC91ST4 all correspond to waters originating in the upper Kelly Creek drainage basin. This area consists of basaltic and rhyolitic volcanic rocks, with the $^{87}Sr/^{86}Sr$ ratios reflecting the young igneous nature of the geology. The ratios are 0.7075, 0.7077, and 0.7076, respectively. Based on the similarities of the ratios it does not appear to matter that the samples represent ground and surface water, as long as they contact a particular rock type. Spring RC91SP1 is in direct subsurface contact with volcanic rocks and, based on the lead isotopes, possibly high uranium limestone, while well BAC-4 and stream RC91ST4 are both influenced by volcanic derived alluvium on the Kelly Creek floodplain.

Jake Creek flows directly on basaltic bedrock in the vicinity of sample RC91ST2. The basalt probably has a strontium isotopic signature that is near the 0.7073 signature of the stream water. Ranch well BAC-8 is located up gradient from RC91ST2, and has a $^{87}Sr/^{86}Sr$ value of 0.7079. The slightly elevated ratio indicates interaction with alluvium, some of which is likely to be weathered sedimentary rocks from erosional windows within the drainage basin.

Spring sites RC91SP3 and RC91SP4 are the only water samples from the Snowstorm Mountains that have strontium ratios that exceed 0.7080. They are also the only samples located near sedimentary erosional windows that are exposed through the volcanic sequence. The Valmy Formation, consisting of chert and siliceous shale, crops out at both localities. Ground-water flow through this sedimentary package is undoubtedly elevating the strontium values to the 0.7085 and 0.7086 levels of the springs.

Site MURD-5, BAC-5, and BAC-6 represent ground waters located in the valley-fill alluvium in the southern parts of the basin. Site MURD-5 has a $^{87}Sr/^{86}Sr$ ratio of 0.7092. The well taps zones of granodiorite gravels that have been weathered from the Osgood Mountains. The higher signature however, indicates some influence from the sedimentary rocks of the range. It is not surprising that the $^{87}Sr/^{86}Sr$ ratio appears to be a mixture of the two. The predominant ground-water flow direction in this area is from the Osgood Mountains where both rock suites are well represented. It is also possible that selective extraction of strontium from granitoid minerals is elevating the isotopic ratio of the water.

Sample site BAC-5 is located next to Kelly Creek and has a $^{87}Sr/^{86}Sr$ ratio of 0.7088. An influence from Kelly Creek is likely lowering the strontium signature of the well water relative to site MURD-5. The creek drains basaltic volcanics, and could be contributing waters with less radiogenic strontium even at this down gradient location. Also, ground water flow at this well is receiving a larger influence from Snowstorm Mountain recharge, which generally has less radiogenic strontium.

The southernmost sample was obtained at Hot Springs Ranch near Evans Creek. It has a $^{87}Sr/^{86}Sr$ ratio of 0.7096. This value seems high considering the Snowstorm Mountain influence that should be present based on proximity to the eastern bordering range. The well at site BAC-6 taps a deep confined source. Perhaps more water interaction with sedimentary rocks occurs at depth. Another consideration is the source of the hot spring water that periodically flows in this area. It might have higher $^{87}Sr/^{86}Sr$ ratios, thereby meaning that leakage along a structural feature or through an aquitard could affect the strontium signature of the well water.

Strontium ratios in waters of Kelly Creek Basin are generally lower in the Snowstorm Mountains, where basaltic volcanics dominate, and higher in the vicinity of crustally derived sedimentary rocks, which commonly occur in the Osgood Mountains. The exceptions are the low values produced in waters that are in contact with the Osgood Mountain Stock. The granodiorite intrusion produces the lowest $^{87}Sr/^{86}Sr$ ratios in the study area.

$^{87}Sr/^{86}Sr$-$^{206}Pb/^{204}Pb$ Plot

The $^{87}Sr/^{86}Sr$ vs. $^{206}Pb/^{204}Pb$ plot (Figure 27) delineates fields that relate to basin location and geology. Isotopically less radiogenic strontium coincides with a relatively elevated lead signature for Snowstorm Mountain samples. A radiogenic increase in both lead and strontium appears to occur for samples in the mining area located in the north-central part of the basin. This probably reflects the isotopic composition of a mining target unit(s) underlying the basin-fill alluvium. The granodiorite field consists of isotopically less radiogenic lead and strontium. An alluvial influence causes the slight variability that is present for sample MURD-5. Sample sites RC91SP3 and BAC-9 do not fall into any of the fields. By location, sample RC91SP3 could be placed in the Snowstorm Mountain field, but atmospheric lead has caused a shift to the isotopically lower end of the lead data spectrum. Sample BAC-9 has a significantly more radiogenic strontium value than any of the other sample sites. This results from ground water flow through old crustally-derived sedimentary rocks. Due to the lack of more samples, no field has been created for this location and/or lithology.

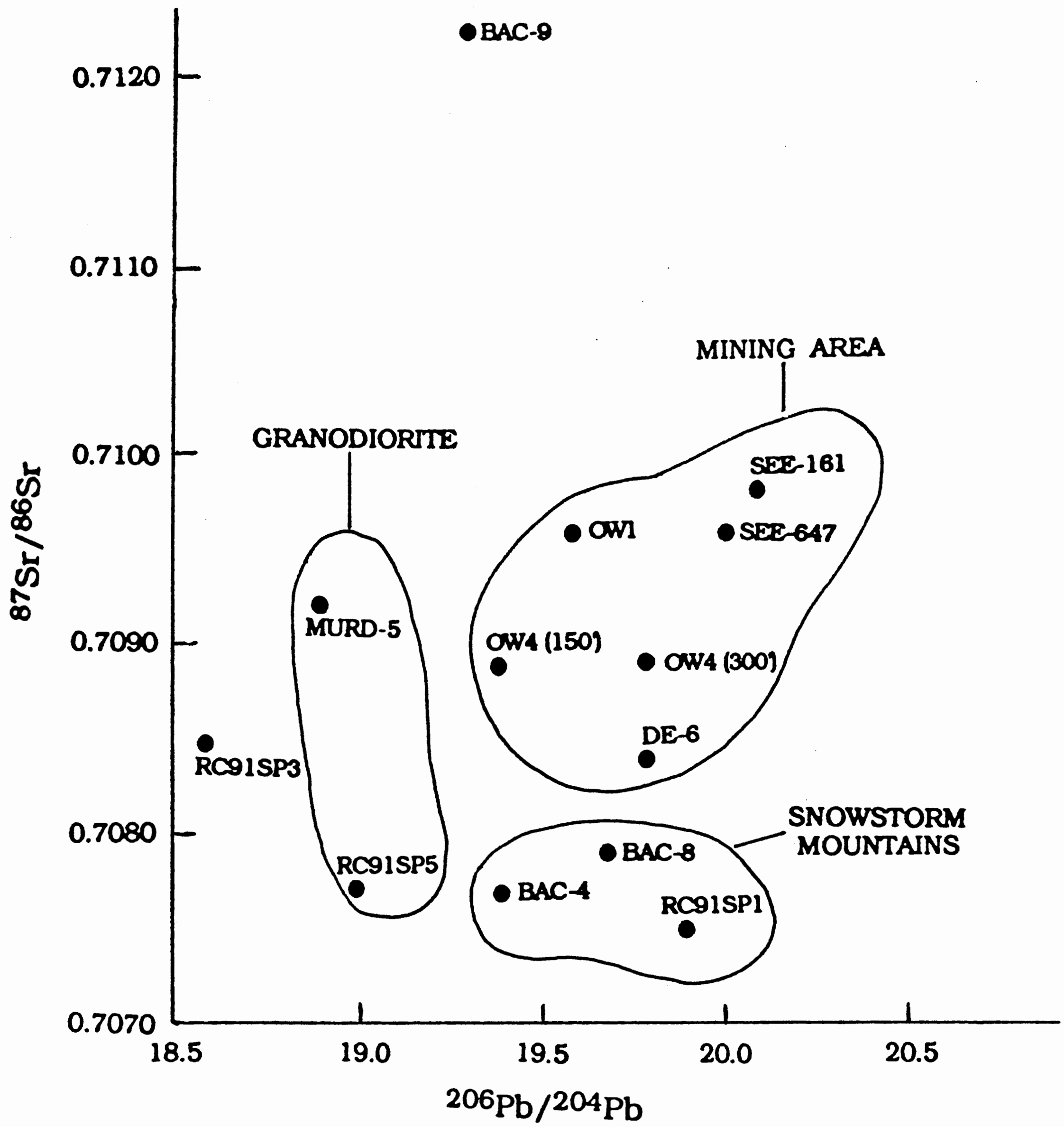


Figure 27. $^{87}Sr/^{86}Sr$ vs. $^{206}Pb/^{204}Pb$ plot.

CHAPTER VIII

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

Discussion

Water-table elevations and water samples were obtained on three visits to the study area. Ground-water data enabled the construction of a potentiometric surface map, and a corresponding flow net for the basin. The water table tends to mimic topography, being higher in the mountains and lower in the valley. Flow generally moves laterally towards Kelly Creek, and southward in the direction of the Humboldt River.

Structural features play a major role in the ground-water flow within the mountains. Many faults, fractures, and joints make hydraulic parameters difficult to determine. Hydraulic conductivity values can vary over several orders of magnitude. The valley-fill, however, is considered a basin-fill alluvial aquifer with average hydraulic conductivity values between 20 and 30 gpd/ft^2. Clay lenses produce locally confined aquifers, but pumping causes a conversion to water-table conditions. Good hydrologic communication exists between the bedrock and the alluvial-fill because of the abundance of structural conduits allowing flow.

Two predominant ground-water flow paths are present in Kelly Creek Basin. Shallow, relatively short flow paths commonly discharge at springs, and are in many cases, related to subsurface structural features. Deep flow paths replenish confined systems at considerable depth within basin-fill alluvium. They result from high elevation recharge that is reflected in their depleted hydrogen and oxygen isotopic signatures.

Water samples were collected and analyzed for various stable and radiogenic isotopes to aid in determining the origin, age, and flow paths of ground water. Hydrogen, oxygen, lead, and strontium are the elements whose isotopic signatures were determined for this task. The meteoric water line (MWL) of Craig (1961) and the local meteoric water line (LMWL) developed for Dixie Valley by Jacobson and others (1983) do not fit the data for Kelly Creek Basin. The non-equilibrium conditions of high temperatures and dryness, resulting in increased rates of evaporation, have caused a shift to the -d parameter side of the MWL (Figure 16).

Recharge occurs from snowmelt at high elevations within the Osgood and Snowstorm Mountains. A more depleted isotopic signature (more negative δD and $\delta^{18}O$) exists for precipitation that falls at increasing elevation (Figure 28). Delta values representing the lightest waters in the basin are δD=-136‰ and $\delta^{18}O$=-17.4‰. Although the highest elevation precipitation was not sampled, it may be as light as -145‰ based on elevation depletion rates developed by Friedman and Smith (1970). Once infiltration occurs, the isotopic signature of that recharge event is set unless unusual subsurface conditions exist. This enables isotopes of hydrogen and oxygen to be good natural tracers.

Waters in close proximity to the surface in this environment are undoubtedly affected by evaporative fractionation. This causes δD and $\delta^{18}O$ values to become more enriched, or heavier. Care must be taken to minimize fractionation during sampling, and in choosing sites whose signatures have not shifted.

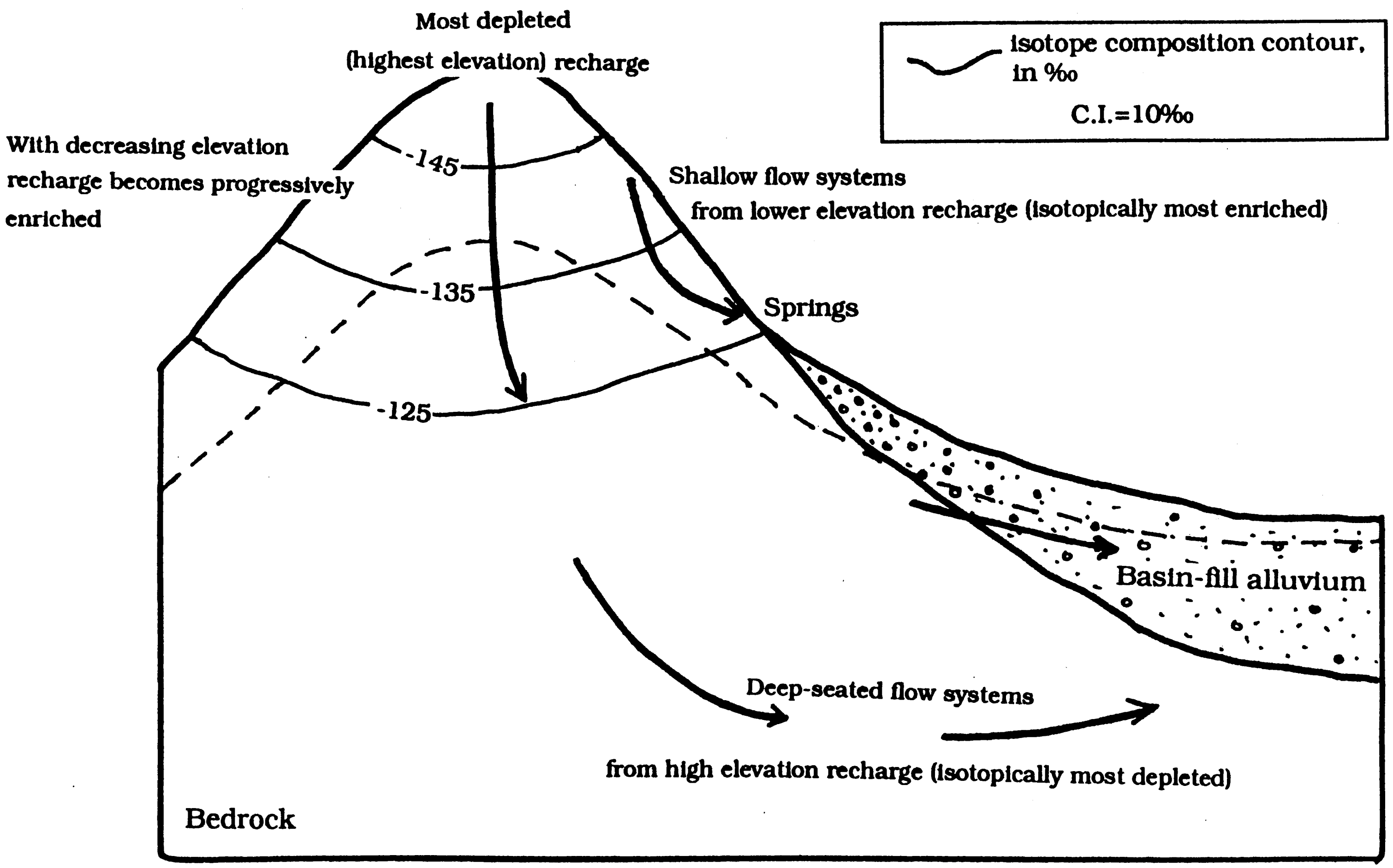


Figure 28. Generalized view of the δD compositional changes of recharge with increasing elevation and of ground-water flow in the Kelly Creek Basin (Dashed line is the potentiometric surface, arrows show direction of ground water flow).

Tritium was analyzed to aid in determining how long the ground water takes to travel from recharge areas to discharge areas. Only one of three samples registered a significant TU quantity. The substantial amount of time needed for water to travel through a basin and range ground water system hinders tritium's tracer qualities.

Lead and strontium isotopic signatures in water reflect those of the rocks with which the waters interact. The unique geologic differences in the ranges bordering the Kelly Creek Basin create a situation where changing signatures in the ground and surface waters correlate to lithologic changes. The most radiogenic $^{206}Pb/^{204}Pb$ signatures of 19.8 or above result from contact with uranium rich source rocks. More depleted values come from atmospheric deposition. Strontium ratios of 0.710 or greater are found in waters flowing through crustally-derived Paleozoic sedimentary rocks. Mantle-derived basalts, and similar igneous rocks that have had minimal influence from crustal material, have $^{87}Sr/^{86}Sr$ ratios of 0.7076 or less.

Isotopically depleted ground waters are found in wells and drill holes of considerable depth within the basin-fill alluvium. This indicates recharge from high elevation precipitation within the bordering ranges via deep seated flow paths (Figure 28). Delta deuterium values range from -130‰ to -136‰. The slight scatter reflects some mixing with heavier, lower elevation recharge waters. Ground waters discharging at springs and shallow wells are dominated by lower elevation recharge as is evident by their heavier isotopic signatures. Delta deuterium values for these waters range from -118‰ to -128‰. Fractionation due to the proximity of the flow to the surface, and the elevation at which the sample was taken, both contribute to the 10‰ range in the isotope signatures. Infiltration rate and flow paths play vital roles in establishing the δD and $\delta^{18}O$ values of Kelly Creek Basin ground waters.

Surface waters in this area are subjected to varying degrees of fractionation depending on the amounts of evaporative fractionation. Stream waters have δD values that range from -108‰ to -121‰. Gaining reaches of drainages tend to maintain fairly stable isotopic signatures owing to the ground-water contribution to the stream. This is generally most substantial at higher elevations and in the spring and early summer. The size, amount of vegetation cover, location of flow (i.e. on bedrock or on alluvium), and gradient also impact isotopic composition. Kelly Creek is the largest stream in the basin and has an isotopic composition that is the least affected by evaporation. Delta deuterium values become depleted by only 2‰ over a 15 mile stretch. Osgood Mountains drainages are all ephemeral and have isotopic compositions that vary considerably based on elevation, vegetation cover, and gradient. Osgood Creek, once out of the tree cover of its tributary valley, became depleted by 6‰ in 1.5 miles. Jake Creek flows directly on basaltic bedrock in the much of the study area. Its relatively enriched δD of 108‰ reflects increased evaporation from elevated temperatures associated with flow on bedrock.

Tritium analyses on ground waters within basin and range hydrologic systems are generally not useful. Residence times of the subsurface flow are too long to enable the transient nature of the isotope to benefit the ground-water study. The isotope's decay rate is too rapid for it to persist from recharge zones to discharge zones. Short flow path springs are the only ground waters that are young enough to register tritium quantities that show the effects of the 'bomb spike'.

Lead and strontium isotopes are very useful in tracing flow that is in contact with particular geologic units. The $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios show an increase to more radiogenic values in a north to northeast direction within the basin. Uranium rich source rocks, generally limestone, are responsible for the most radiogenic signatures. They are indicated by $^{206}Pb/^{204}Pb$ ratios of greater than 19.5. Igneous rocks and basin-fill alluvium produce intermediate $^{206}Pb/^{204}Pb$ values, usually between 19.0 and 19.5. Finally $^{206}Pb/^{204}Pb$ ratios resulting from atmospheric deposition make up the least radiogenic samples at 18.6 to 18.8.

Strontium isotopic ratios show correlations to geology in a similar manner to lead. Waters in contact with crustally-derived sedimentary rocks have $^{87}Sr/^{86}Sr$ ratios of greater than 0.710. The Preble Formation, in the Osgood Mountains, produces waters of this nature with a strontium signature of 0.7123. Rocks that have depleted $^{87}Sr/^{86}Sr$ ratios (0.704-0.707) usually suggest a deep, upper mantle source. Basalts of the Snowstorm Mountains and the Osgood Mountain Stock (granodiorite) are examples of strontium depleted rocks. Waters in contact with the stock contained the lowest strontium isotopic ratios in the basin at 0.7071. Waters in contact with the basalts were slightly higher at 0.7073 to 0.7079.

Stable and radiogenic isotopes are very useful in determining the origin and flow paths of ground water. The relative enrichment or depletion of hydrogen and oxygen isotopes can be an indication of recharge elevations and/or climatic conditions that existed at the time of infiltration. The radiogenic isotopes of lead and strontium aid in tracing flow paths of ground water because the isotopic signature of the water is a reflection of the isotopic signature of the rocks with which the water is in contact. The tracer quality of radiogenic isotopes has proved vital in following ground waters through particular rock types within the Kelly Creek Basin.

Conclusions

1. Ground water in the Kelly Creek Basin is recharged in the bordering ranges above 5,700 ft. Two components of ground-water flow exist in the valley; lateral flow in the direction of Kelly Creek and southward flow to the Humboldt River. All streams in the basin are ephemeral and are usually fed by springs at upper elevations.

2. Hydraulic parameters are extremely variable. Structural features can cause hydraulic conductivity and transmissivity to vary over many orders of magnitude within the bedrock. The basin-fill alluvium is in good hydrologic communication with bedrock because of numerous joints and fractures that enable flow. Clay lenses produce locally confined conditions to exist in the basin-fill.

3. Most depleted stable isotopic signatures indicate that high elevation recharge or recharge from a time of differing climatic conditions supplied the water to the deep confined systems within the basin. These are old waters (>100 years) that have travelled long deep flow paths. Younger, shorter flow path ground waters are found at springs within the ranges. They have relatively enriched stable isotopic signatures, indicative of lower elevation recharge. They also contain tritium concentrations that could be representative of the 'bomb spike' produced by thermonuclear weapons testing.

4. The lead and strontium radiogenic isotopic signatures in waters

reflect the radiogenic signature of the rocks with which the water is in contact. $^{206}Pb/^{204}Pb$ ratios greater than 19.5 indicate an old uranium-rich source rock, commonly limestone, while ratios between 18.6 and 18.8 are more indicative of aeolian atmospheric deposition. A general increase in the radiogenic signature of lead occurs in a north to north-east direction within the basin. $^{87}Sr/^{86}Sr$ ratios of waters in contact with Paleozoic sedimentary rocks are greater than 0.710, indicative of an upper mantle, relatively rubidium-rich source. Ratios in the vicinity of 0.707 reflect water contact with a mid to lower mantle source rock that has had little to no interaction with the crust. The Osgood Mountain Stock and the basalts of the Snowstorm Mountains produce these low strontium ratio waters.

Recommendations

Future work that would aid in the understanding of the hydrogeologic conditions of the Kelly Creek Basin are 1.) more precipitation sampling, 2.) greater density of water-table data within the mountain ranges, and 3.) better control on the trace element radiogenic signatures of the rocks throughout the basin.

Snow coring at different elevations in both ranges would greatly constrain the isotopic signatures of particular recharge areas. This could help in determining a more complete view of the flow paths of ground waters. Rain gages on the valley floor could collect low elevation precipitation. The isotopic signatures could be compared to shallow mid-valley ground waters in an effort to determine if basinal rains play a role in recharge.

The controls on the water table are very loose above the 5,500 ft. elevation level in each of the bordering ranges. The feasibility of observation wells being installed to monitor ground water, however, is very limited. Deep exploration boreholes could be used to obtain the needed water-table information if drilling within the mountains ever took place.

Knowledge of the lead and strontium ratios of particular rock types within the basin would aid in the ability to trace water flow through the subsurface. It would create a better understanding of how a water had acquired its trace element isotopic signature. This could also aid in determining subsurface stratigraphy based on water ratio-rock ratio correlations.

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APPENDICES

APPENDIX A
DRILLER'S LOGS

WELL LOG AND REPORT TO THE STATE ENGINEER OF NEVADA

PLEASE COMPLETE THIS FORM IN ITS ENTIRETY

Log No. 4369
Rec. Jan 26
Well No. 5
Permit No. —
Do not fill in

Owner Gene & Jo Christison Driller W. L. McDonald

Address P. O. Box 26; Golconda, Nevada Address 1720 Trabert ; Sparks, Lic. No. 494

Location of well: NE ¼ SW ¼ Sec. 24, T. 37N/S, R. 41E, in Humboldt County

or approx. 50' North of existing well at existing ranch house

Water will be used for irrigation purposes mainly Total depth of well 200'

Size of drilled hole 10" Weight of casing per linear foot 21.15 lbs.

Thickness of casing .188 wall Temp. of water normal

Diameter and length of casing 10" I.D. in random lenghths to 22'
(Casing 12" in diameter and under give inside diameter; casing 12" in diameter give outside diameter.)

If flowing well give flow in c.f.s. or g.p.m. and pressure ---

If nonflowing well give depth of standing water from surface 15'

If flowing well describe control works ------ (Type and size of valve, etc.)

Date of commencement of well 11-18-66 Date of completion of well 12-4-66

Type of well rig Cable tool Bucyrus Erie 22-W

LOG OF FORMATIONS

From feet	To feet	Thickness feet	Type of material
0	1	1	Loamy topsoil
1	4	3	Hard yellow clay w/ large rounded gravels to 3"
4	52	48	Hard yellow clay w/ semi-rounded gravels to ½" mixed
52	60	8	Firm yellow clay
60	73	13	Firm yellow clay w/ some small rounded gravels to 3/8" mixed
73	78	5	Soft sandy yellow clay
78	97	19	Firm yellow clay w/ small rounded gravels to ½" mixed
97	120	23	Fine to coarse sand w/ approx. 2% silt & semi-rounded to rounded gravels to ½"
120	135	15	Same as above only w/ gravels to 3/8"
135	140	5	Soft sandy yellow clay
140	145	5	Fine to coarse sand w/ semi-rounded gravels to 3/8"- some inconsistant sticky yellow clay lenses
145	165	20	Hard & soft sandy yellow clay w/ some semi-rounded gravels to ½" mixed

Water-bearing Formation, Casing Perforations, Etc.

Chief aquifer (water-bearing formation)
from 55 to 165 ft.

Other aquifers ---
Formation extremely difficult to pin-point exact aquifers

First water at 52-60 feet.

Casing perforated
from 55 to 195 ft.

Size of perforations
1/8" x 6"
3 per row/1 row every 12"
by Oxy-acet. torch

(OVER)

919

LOG OF FORMATIONS—*Continued*

From feet	To feet	Thickness	Type of material
165	185	20	Fine to coarse sand w/ semi-rounded gravels to 3/8" & sticky yellow clay sometimes mixed
185	200	15	Fine to coarse sand w/ rounded gravels to 3/8"- mainly mixed with sticky yellow clay

CASING RECORD

Diam. casing	From feet	To feet	Length	"Remarks"—Seals, Grouting, Etc.
0	- 200	2000	10" ID	A natural mud seal was effectively constructed from -2' to +34'.

GENERAL INFORMATION—Pumping Test, Quality of Water, Etc.

The well was bailed for a two hour continuous period yielding 4 GPM from the 125' level. The water appeared to be of satisfactory quality and was sand free.

WELL DRILLER'S STATEMENT

This well was drilled under my jurisdiction and the above information is true to my best information and belief.

Signed W. L[illegible] Well Driller

By

License No. 494

Dated December 20, 1966

(Not to be filled in by Driller)

DIVISION OF WATER RESOURCES

STATE OF NEVADA
DIVISION OF WATER RESOURCES

OFFICE USE
Log No. 970
Permit No. 226
Basin

8

WELL DRILLERS REPORT

Please complete this form in its entirety

OWNER JIM WALLACE ADDRESS 1473 West [illegible] [illegible], Calif.

2. LOCATION [illegible] ¼ NE ¼ Sec. 10 T. 37 N/S R. 42 E HUMBOLDT County
PERMIT NO. 22655

3. TYPE OF WORK
New Well ☒ Recondition ☐
Deepen ☐ Other ☐

4. PROPOSED USE
Domestic ☐ Irrigation ☒ Test ☐
Municipal ☐ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☒ Rotary ☐
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
TOPSOIL		0	6	6
BR. SANDY CLAY		6	28	22
BR. CLAY		28	56	28
SAND + GRAVEL	✓	56	71	15
BR. SANDY CLAY		71	82	11
LIGHT BLUE CLAY		82	122	
GRAY CLAY		122	146	
SAND + PEA GRAVEL	✓	146	157	
HARD BR. CLAY		157	228	
SAND + PEA GRAVEL	✓	228	233	
BR. CLAY		233	236	
SAND + PEA GRAVEL	✓	236	242	
HARD BR. CLAY		242	318	
SAND + PEA GRAVEL	✓	318	326	
BR. CLAY		326	342	
SAND + PEA GRAVEL	✓	342	348	
BRO. CLAY		348	390	
SAND + PEA GRAVEL	✓	390	401	
HARD BR. CLAY.		401	540	

Date started AUG. 25, 1967
Date completed SEPT. 3, 1967

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
	1680	238	12 hrs.

BAILER TEST

G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

8. WELL CONSTRUCTION

Diameter hole 16 inches Total depth 540 feet
Casing record 428 ft.
Weight per foot 44 lb. Thickness ¼"

Diameter	From	To
16 inches	0 feet	428 feet
inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet

Surface seal: Yes ☐ No ☒ Type
Depth of seal feet
Gravel packed: Yes ☐ No ☒
Gravel packed from feet to feet

Perforations:
Type perforation MILLS
Size perforation ⅜ x 2"
From 222 feet to feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

9. WATER LEVEL

Static water level 28 Feet below land surface
Flow G.P.M.
Water temperature ° F. Quality Good

10. DRILLERS CERTIFICATION

This well was drilled under my supervision and the report is true to the best of my knowledge.

Name Armstrong Bros.
Address P.O. Box 487
Nevada contractor's license number 5348
Nevada driller's license number 527
Signed Joe L. Armstrong
Date Sept. 19 - 1967

USE ADDITIONAL SHEETS IF NECESSARY

5471

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

PRINT OR TYPE ONLY

OFFICE USE ONLY
Log No. 30834
Permit No.
Basin 66

12

NOTICE OF INTENT NO. 10177

1. OWNER FirstMiss Gold Inc.
MAILING ADDRESS P.O. Box 220
Golconda, Nevada 89414

ADDRESS AT WELL LOCATION
Getchell Mine
Well #88-MM-W1 / Drill Site #1

2. LOCATION NE ¼ NW ¼ Sec. 3 T. 38 N/S R. 42 E Humboldt County
PERMIT NO. W-M0113 (Issued by Water Resources) | Parcel No. | Subdivision Name

3. TYPE OF WORK: New Well ☒ Recondition ☐ Deepen ☐ Other ☐

4. PROPOSED USE: Domestic ☐ Irrigation ☐ Test ☒ Municipal ☐ Industrial ☐ Stock ☐

5. TYPE WELL: Cable ☐ Rotary ☒ Other ☐ Air

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
unconsolidated rock		0	30	
consolidated rock		30	89	
alluvium		89	90	
consolidated rock fractures		90	130	

Date started OCTOBER 10, 19 88
Date completed OCTOBER 20, 19 88

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump

BAILER TEST

G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours

8. WELL CONSTRUCTION

Diameter 9-7/8 inches Total depth 130 feet
Casing record 4" PVC Schedule 80 T&C
Weight per foot 2.86 Thickness

Diameter	From	To
4 inches	+1 feet	130 feet

Surface seal: Yes ☒ No ☐ Type neat cement
Depth of seal 42 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 45 feet to 130 feet
10 to 20 Mesh Silica Sand

Perforations:
Type perforation 4" PVC Well Screen
Size perforation .020"
From 50 feet to 130 feet

9. WATER LEVEL

Static water level 27 feet below land surface
Flow ____ G.P.M. ____ P.S.I.
Water temperature ____ °F Quality ____

10. DRILLER'S CERTIFICATION

This well was drilled under my supervision and the report is true to the best of my knowledge.

Name SARGENT IRRIGATION COMPANY (Contractor)
Address 9955 N. Virginia St., Reno, Nevada (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 21246
Nevada contractor's driller's number issued by the Division of Water Resources 1391
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1593/1476
Signed [signature] (By driller performing actual drilling on site or contractor)
Date JANUARY 16, 1989

USE ADDITIONAL SHEETS IF NECESSARY

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

PRINT OR TYPE ONLY

OFFICE USE ONLY
Log No. 30885
Permit No.
Basin 66

14

NOTICE OF INTENT NO. 10177

1. OWNER FirstMiss Gold Inc.
MAILING ADDRESS P.O. Box 220
Golconda, Nevada 89414

ADDRESS AT WELL LOCATION
Getchell Mine
Well #88-TIMW-1 / Drill Site #2

2. LOCATION SE ¼ NW ¼ Sec. 27 T 38 N/S R. 42 E Humboldt County
PERMIT NO. W-MO113 (Issued by Water Resources) | Parcel No. | Subdivision Name

3. TYPE OF WORK	4. PROPOSED USE	5. TYPE WELL
New Well ☒ Recondition ☐ Deepen ☐ Other ☐	Domestic ☐ Irrigation ☐ Test ☒ Municipal ☐ Industrial ☐ Stock ☐	Cable ☐ Rotary ☒ Other ☐ Air

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
unconsolidated rock		0	50	
consolidated rock		50	60	
unconsolidated rock		60	90	
consolidated rock, fractured black rock		90	140	
consolidated black rock		140	190	

Date started OCTOBER 20, 1988
Date completed OCTOBER 26, 1988

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump

BAILER TEST

G.P.M. ______ Draw down ______ feet ______ hours
G.P.M. ______ Draw down ______ feet ______ hours
G.P.M. ______ Draw down ______ feet ______ hours

8. WELL CONSTRUCTION

Diameter 9-7/8 inches Total depth 190 feet
______ inches
______ inches
Casing record 4" PVC Schedule 80 T&C
Weight per foot 2.86 Thickness

Diameter	From	To
4 inches	+1 feet	190 feet

Surface seal: Yes ☒ No ☐ Type neat cement
Depth of seal 102 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 105 feet to 190 feet
10 to 20 Mesh Silica Sand

Perforations:
Type perforation 4" PVC Well Screen
Size perforation .020"
From 110 feet to 190 feet
From ______ feet to ______ feet
From ______ feet to ______ feet
From ______ feet to ______ feet
From ______ feet to ______ feet

9. WATER LEVEL

Static water level 85 feet below land surface
Flow ______ G.P.M. ______ P.S.I.
Water temperature ______ °F Quality ______

10. DRILLER'S CERTIFICATION

This well was drilled under my supervision and the report is true to the best of my knowledge.

Name SARGENT IRRIGATION COMPANY (Contractor)
Address 9955 N. Virginia St., Reno, Nevada (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 21246
Nevada contractor's driller's number issued by the Division of Water Resources 1391
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1593/1476
Signed [illegible] (By driller performing actual drilling on site or contractor)
Date January 16, 1989

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

PRINT OR TYPE ONLY

OFFICE USE ONLY
Log No. 30734
Permit No.
Basin 66

16

NOTICE OF INTENT NO. 9702

1. OWNER PINSON MINING COMPANY
ADDRESS AT WELL LOCATION PINSON MINE
MAILING ADDRESS P. O. BOX 192
WINNEMUCCA, NEVADA 89445

2. LOCATION SW ¼ SW ¼ Sec. 28 T. 38 (N)/S R. 42 E HUMBOLDT County
PERMIT NO. W-243 /51390 (Issued by Water Resources) | Parcel No. | Subdivision Name

3. TYPE OF WORK
New Well ☒ Reconditon ☐ Deepen ☐ Other ☐

4. PROPOSED USE PW# 10
Domestic ☐ Irrigation ☐ Test ☐ Municipal ☐ Industrial ☒ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒ Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
sand & clay		0	35	35
broken rock & clay				
shale		35	325	190
solid rock		325	340	15
black shale rock		340	410	70
medium dense black				
rock		410	580	170
very dense black rock				
hard		580	730	150
Electric geophysical well log				
by: GEO-HYDRO DATA				

'88 DEC 12 AM 11:02
RECEIVED
STATE ENGINEERS OFFICE

Date started DECEMBER 3, 1987
Date completed DECEMBER 18, 1987

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
air lift	20		8

BAILER TEST
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours

8. WELL CONSTRUCTION
Diameter 14 inches Total depth 542 feet
Casing record 8-5/8" O.D. x .250" wall
Weight per foot 22.36 Thickness

Diameter	From	To
8 inches	+1 feet	542 feet

Surface seal: Yes ☒ No ☐ Type cement sand grout
Depth of seal 50 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 50 feet to 542 feet
Wadsworth 7/16" minus well rock
Perforations:
Type perforation Milled
Size perforation 3" x 3/32" dbl std spacing
From 242 feet to 542 feet

9. WATER LEVEL
Static water level 280 feet below land surface
Flow ____ G.P.M. ____ P.S.I.
Water temperature 66 °F Quality good

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name SARGENT IRRIGATION COMPANY (Contractor)
Address 9955 N. VIRGINIA ST. RENO, NV 89506 (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 21246
Nevada contractor's driller's number issued by the Division of Water Resources 1391
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1491
Signed [signature] By driller performing actual drilling on site or contractor
Date JANUARY 20, 1988

(Rev. 11-85) USE ADDITIONAL SHEETS IF NECESSARY

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

PRINT OR TYPE ONLY

OFFICE USE ONLY
Log No. 30736
Permit No.
Basin 66

18

NOTICE OF INTENT NO. 9700

1. OWNER PINSON MINING COMPANY
MAILING ADDRESS P. O. BOX 192
WINNEMUCCA, NEVADA 89445

ADDRESS AT WELL LOCATION
PINSON MINE

2. LOCATION NE ¼ NE ¼ Sec. 33 T. 38 (N) S R. 42 E HUMBOLDT County
PERMIT NO. W-243 / 51388 (Issued by Water Resources) | Parcel No. | Subdivision Name.

3. TYPE OF WORK
New Well ☒ Recondition ☐
Deepen ☐ Other ☐

4. PROPOSED USE PW#8
Domestic ☐ Irrigation ☐ Test ☐
Municipal ☐ Industrial ☒ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
clay & fine gravel		0	30	30
clay & fine gravel with broken rock		30	180	150
large gravel & sand little clay		180	190	10
medium to fine gravel & sand w/broken rock		190	250	60
clay & gravel layers		250	350	100
sand & gravel w/trace of clay		350	450	100
sand, fine gravel w/trace of clay		450	465	15
fine sand		465	470	5
fine sand to clay		470	475	5
fine sand, medium gravel & clay		475	490	15
medium to fine sand & clay		490	583	93
Electric geophysical well log by: GEO-HYDRO DATA				

DEC 22 A11:02

Date started OCTOBER 19, 1987
Date completed DECEMBER 8, 1987

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
	400	32½	2
	550	75	2
	700	138½	2
	800	143	20 min.
	647	117	71

BAILER TEST

G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours

8. WELL CONSTRUCTION

Diameter 18 inches Total depth 583 feet
____ inches
____ inches

Casing record 12-3/4" O.D. x .250 wall
Weight per foot 33.38 Thickness ____

Diameter	From	To
12 inches	+1 feet	583 feet
inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet

Surface seal: Yes ☒ No ☐ Type cement sand grout
Depth of seal 50 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 50 feet to 583 feet
CHEVREAUX 1/8" x 1/4" quartz pebbles

Perforations:
Type perforation JOHNSON H-C mild steel .080" slot
Size perforation Milled 3" x 1/8" dbl std spacin
From perf 210-280 feet to scn 280-320 feet
From 320-360 /400-420 feet to 360-400 /420-440 feet
From 440-460 /480-500 feet to 460-480 /500-520 feet
From 520-540/ 560-570 feet to 540-560 feet
From ____ feet to ____ feet

9. WATER LEVEL

Static water level 210 feet below land surface
Flow ____ G.P.M. ____ P.S.I.
Water temperature 65 °F Quality good

10. DRILLER'S CERTIFICATION

This well was drilled under my supervision and the report is true to the best of my knowledge.

Name SARGENT IRRIGATION COMPANY (Contractor)
Address 9955 N. VIRGINIA ST. RENO, NV 89506 (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 21246
Nevada contractor's driller's number issued by the Division of Water Resources 1391
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1491
Signed [signature] (By driller performing actual drilling on site or contractor)
Date JANUARY 20, 1988

(Rev. 11-85) USE ADDITIONAL SHEETS IF NECESSARY

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

OFFICE USE ONLY
Log No. 30846
Permit No.
Basin

20

NT OR TYPE ONLY

NOTICE OF INTENT NO. 10177

1. OWNER FirstMiss Gold Inc.
MAILING ADDRESS P.O. Box 220
Golconda, Nevada 89414

ADDRESS AT WELL LOCATION
Getchell Mine
Well #TIMW-9 / Drill Site #8

2. LOCATION SE ¼ NE ¼ Sec. 22 T 39 N/S R. 42 E Humboldt County

PERMIT NO. W-M0113 (Issued by Water Resources) | Parcel No. | Subdivision Name

3. TYPE OF WORK	4. PROPOSED USE	5. TYPE WELL
New Well [X] Recondition [ ] Deepen [ ] Other [ ]	Domestic [ ] Irrigation [ ] Test [X] Municipal [ ] Industrial [ ] Stock [ ]	Cable [ ] Rotary [X] Other [ ] Air

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
clay		0	10	
hard consolidated rock		10	120	
consolidated rock		120	170	
black consolidated rock		170	250	

Date started NOVEMBER 18, 19 88
Date completed NOVEMBER 22, 19 88

8. WELL CONSTRUCTION

Diameter 9-7/8 inches Total depth 250 feet

Casing record 4" PVC Schedule 80 T&C
Weight per foot 2.86 Thickness

Diameter	From	To
4 inches	+1 feet	250 feet

Surface seal: Yes [X] No [ ] Type neat cement
Depth of seal 222 feet
Gravel packed: Yes [X] No [ ]
Gravel packed from 225 feet to 250 feet
10 to 20 Mesh Silica Sand

Perforations:
Type perforation 4" PVC Well Screen
Size perforation .020"
From 230 feet to 250 feet

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump

BAILER TEST

G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

9. WATER LEVEL

Static water level 212 feet below land surface
Flow G.P.M. P.S.I.
Water temperature °F Quality

10. DRILLER'S CERTIFICATION

This well was drilled under my supervision and the report is true to the best of my knowledge.

Name SARGENT IRRIGATION COMPANY (Contractor)
Address 9955 N. Virginia St., Reno, Nevada (Contractor)

Nevada contractor's license number issued by the State Contractor's Board 21246

Nevada contractor's driller's number issued by the Division of Water Resources 1391

Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1593/1476

Signed [signature] By driller performing actual drilling on site or contractor

Date JANUARY 16, 1989

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

IT OR TYPE ONLY

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Log No. 30842
Permit No.
Basin

23

NOTICE OF INTENT NO. 10177

1. OWNER FirstMiss Gold Inc.
MAILING ADDRESS P.O. Box 220
Golconda, Nevada 89414

ADDRESS AT WELL LOCATION
Getchell Mine
Well #TIMW-2 / Drill Site #3

2. LOCATION SE ¼ NW ¼ Sec. 26 T. 39 N/S R. 42 E Humboldt County

PERMIT NO. W-M0113 (Issued by Water Resources) | Parcel No. | Subdivision Name

3. TYPE OF WORK	4. PROPOSED USE	5. TYPE WELL
New Well ☒ Recondition ☐ Deepen ☐ Other ☐	Domestic ☐ Irrigation ☐ Test ☒ Municipal ☐ Industrial ☐ Stock ☐	Cable ☐ Rotary ☒ Other ☐ Air

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
clays		0	10	
consolidated rock		10	250	
shale		250	255	

Date started OCTOBER 26, 19 88
Date completed NOVEMBER 3, 19 88

8. WELL CONSTRUCTION

Diameter 9-7/8 inches Total depth 255 feet
Casing record 4" PVC Schedule 80 T&C
Weight per foot 2.86 Thickness

Diameter	From	To
4 inches	+1 feet	255 feet

Surface seal: Yes ☒ No ☐ Type neat cement
Depth of seal 187 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 190 feet to 255 feet
10 to 20 Mesh Silica Sand

Perforations:
Type perforation 4" PVC Well Screen
Size perforation .020"
From 195 feet to 255 feet

9. WATER LEVEL

Static water level 182 feet below land surface
Flow G.P.M. P.S.I.
Water temperature °F Quality

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump

BAILER TEST

G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

10. DRILLER'S CERTIFICATION

This well was drilled under my supervision and the report is true to the best of my knowledge.

Name SARGENT IRRIGATION COMPANY (Contractor)
Address 9955 N. Virginia St., Reno, Nevada (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 21246
Nevada contractor's driller's number issued by the Division of Water Resources 1391
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1593/1476
Signed January 16, 1989 (By driller performing actual drilling on site or contractor)
Date

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLERS REPORT

Please complete this form in its entirety

OFFICE USE
Log No. 26
Permit No.
Basin 66

PRINT OR TYPE ONLY

NOTICE OF INTENT NO. 24[illegible]

OWNER Robert Palm
ADDRESS AT WELL LOCATION Kelly Creek
MAILING ADDRESS

2. LOCATION NW ¼ NW ¼ Sec. 14 T. 39 N N/S R. 43 E Humboldt County
PERMIT NO. (Issued by Water Resources) | Parcel No. | Subdivision Name

3. TYPE OF WORK
New Well ☐ Recondition ☐
Deepen ☐ Other ☐

4. PROPOSED USE
Domestic ☒ Irrigation ☐ Test ☐
Municipal ☐ Industrial ☐ Stock ☐

5. TYPE WELL
Cable ☒ Rotary ☐
Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Sandy Top Soil		0	5	5
Gravel in Clay		5	10	5
Sand Gravel		10	17	7
Yellow Clay w/Sand & Gravel		17	35	18
Hard Clay & Rocks		35	39	4
Sandy Brown Clay		39	70	31
Sandy Yellow Clay w/s Gravel Stringers		70	120	50

Date started 4 March 1986
Date completed 19 March 1986

8. WELL CONSTRUCTION
Diameter hole 6 5/8 inches Total depth 120 feet
Casing record
Weight per foot Thickness .156

Diameter	From	To
6 5/8 inches	0 feet	120 feet
inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet
inches	feet	feet

Surface seal: Yes ☒ No ☐ Type Cement
Depth of seal 50 Ft. feet
Gravel packed: Yes ☐ No ☒
Gravel packed from feet to feet

Perforations:
Type perforation SAW cut
Size perforation
From 100 feet to 120 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

9. WATER LEVEL
Static water level 8 feet below land surface
Flow Bailed 30 gallons G.P.M. P.S.I.
Water temperature Cold °F. Quality Good

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump

BAILER TEST
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours
G.P.M. Draw down feet hours

10. DRILLERS CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name (Contractor)
Address (Contractor)
Nevada contractor's license number 5348
Nevada contractor's drillers number
Nevada driller's license number 795 (Actual Driller)
Signed [signature] (Contractor)
Date 3-28-86

USE ADDITIONAL SHEETS IF NECESSARY

(Rev 6-81)

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY

STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety

PRINT OR TYPE ONLY

OFFICE USE ONLY
Log No. 32113
Permit No.
Basin

29

NOTICE OF INTENT NO. 54096

OWNER Santa Fe Pacific Mining
ADDRESS AT WELL LOCATION
MAILING ADDRESS Box 27019, Albuquerque, NM 87125 — Rabbit Creek, WW #4, NE Golconda, Nevada

2. LOCATION NE ¼ NW ¼ Sec. 29 T 39 N/S R. 43 E Humboldt County
PERMIT NO. 52048 (Issued by Water Resources) | Parcel No. | Subdivision Name

3. TYPE OF WORK
New Well ☒ Recondition ☐ Deepen ☐ Other ☐

4. PROPOSED USE
Domestic ☐ Irrigation ☐ Test ☐ Municipal ☐ Industrial ☒ Stock ☐

5. TYPE WELL
Cable ☐ Rotary ☒ Other ☐

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
fractured rock & gravel		0	65	65
volcanic formations		65	168	103
gravel, fracture rock		168	215	47
sand, gravel, fracute rock		215	225	10
hard rock		225	320	95
gravel, fracture rock		320	360	40
fracture rock, gravel		360	402	42
gravel, fracture rock, clay		402	433	31
fracture rock		433	500	67
fracture rock & clay		500	505	5
clay & fracture rock		505	525	20
clay brown & white		525	550	25
gravel & clay		550	557	7
sand, clay, little fracture rock		557	565	8
sand, gravel little clay		565	645	80
sticky clay		645	650	5
clay & gravel		650	660	10

Date started July 23, 1989
Date completed August 1, 1989

7. WELL TEST DATA

Pump RPM	G.P.M.	Draw Down	After Hours Pump
	1003	205	15

BAILER TEST
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours
G.P.M. ____ Draw down ____ feet ____ hours

8. WELL CONSTRUCTION
Diameter 14 inches Total depth 660 feet
Casing record 14 O.D. x .250
Weight per foot ____ Thickness ____

Diameter	From	To
14 inches	+2 feet	660 feet

Surface seal: Yes ☒ No ☐ Type cement grout
Depth of seal 50 feet
Gravel packed: Yes ☒ No ☐
Gravel packed from 50 feet to 655 feet

Perforations:
Type perforation Johnson Hi-Cap WR X WR
Size perforation
From 187 feet to 470 feet
From 470 feet to 655 feet

9. WATER LEVEL
Static water level 74 feet below land surface
Flow ____ G.P.M. ____ P.S.I.
Water temperature 55 °F Quality ____

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name Sargent Irrigation Company (Contractor)
Address P.O. Box 2646, Elko, Nevada 89801 (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 21246
Nevada contractor's driller's number issued by the Division of Water Resources 1391
Nevada driller license number issued by the Division of Water Resources, the on-site driller 1493
Signed [signature] By driller performing actual drilling on site or contractor
Date August 30, 1989

(Rev. 11-85) USE ADDITIONAL SHEETS IF NECESSARY

APPENDIX B

ISOTOPE DATA

Sample ID	Lat./Long.*	Date Collected	δD_{SMOW}(‰)	$\delta^{18}O_{SMOW}$(‰)	$^{206}Pb/^{204}Pb$
BAC-4	14 30/06 38	2-16-91	-122.83		19.404
BAC-5	04 54/09 57	6-11-91	-125.13		
BAC-6	02 58/05 49	6-12-91	-136.00	-17.4	
BAC-8	12 50/02 10	2-16-91	-120.36		19.689
BAC-9	10 18/15 12	2-16-91	-122.03		19.321
DE-6		2-14-91	-126.63	-15.4	19.814
DE-36		2-14-91	-132.68		
MURD-5	06 46/13 12	6-11-91	-126.26	-16.3	18.905
OW1		2-15-91	-130.12		19.614
OW4 (150')		2-15-91	-128.13		19.382
OW4 (300')		2-15-91	-128.09		19.793
RC91RN		2-16-91	-94.57		
RC91RV		2-16-91	-84.88		
RC91SN1	17 10/04 38	2-15-91	-107.07		
RC91SN2	17 21/00 54	2-15-91	-128.65		
RC91SP1	17 39/00 58	2-15-91	-121.59	-15.6	19.860
RC91SP2	17 51/02 04	2-15-91	-123.86		
RC91SP3	14 16/02 43	6-11-91	-125.44	-15.1	18.632
RC91SP4	14 45/04 04	6-12-91	-125.60		
RC91SP5	09 03/15 58	6-13-91	-120.19		19.034
RC91SP6	10 00/17 04	6-13-91	-118.16	-15.4	
RC91SP7	11 09/15 54	6-14-91	-118.09		
RC91SP8	12 23/16 19	6-14-91	-122.81		
RC91SP9	12 26/16 29	6-14-91	-122.65		
RC91SP10	14 05/16 17	6-15-91	-126.71	-16.1	

Sample ID	Lat./Long.*	Date Collected	δD_{SMOW}(‰)	$\delta^{18}O_{SMOW}$(‰)	$^{206}Pb/^{204}Pb$
RC91ST1	17 12/04 38	2-15-91	-119.96		
RC91ST2	11 15/03 24	6-11-91	-108.03		
RC91ST3	06 33/09 28	6-12-91	-118.07		
RC91ST4	11 39/09 05	6-12-91	-119.37		
RC91ST5	09 50/15 40	6-13-91	-118.76		
RC91ST6	09 55/17 05	6-13-91	-117.50		
RC91ST7	10 33/16 06	6-13-91	-121.04		
RC91ST8	09 13/14 14	6-13-91	-113.35	-14.7	
RC91ST9	11 14/16 03	6-14-91	-116.53		
SEE-161		2-14-91	-135.68	-17.0	20.090
SEE-630		2-14-91	-127.84		
SEE-647		2-14-91	-127.77	-16.3	20.043
91-124	13 48/11 27	6-15-91	-130.22	-16.1	

* Numbers represent minutes and seconds for latitude and longitude, respectively. The degree values are the same for all samples. Latitude is 41° and longitude is 117°.

Sample ID	Lat./Long.*	Date Collected	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{87}Sr/^{86}Sr$
BAC-4	14 30/06 38	2-16-91	15.707	38.769	0.70766
BAC-5	04 54/09 57	6-11-91			0.70882
BAC-6	02 58/05 49	6-12-91			0.70959
BAC-8	12 50/02 10	2-16-91	15.720	38.936	0.70789
BAC-9	10 18/15 12	2-16-91	15.704	38.726	0.71227
DE-6		2-14-91	15.746	39.027	0.70840
DE-36		2-14-91			
MURD-5	06 46/13 12	6-11-91	15.656	38.446	0.70918
OW1		2-15-91	15.728	38.886	0.70959
OW4 (150')		2-15-91	15.686	38.720	0.70888
OW4 (300')		2-15-91	15.740	39.048	0.70886
RC91RN		2-16-91			
RC91RV		2-16-91			
RC91SN1	17 10/04 38	2-15-91			
RC91SN2	17 21/00 54	2-15-91			
RC91SP1	17 39/00 58	2-15-91	15.746	39.083	0.70746
RC91SP2	17 51/02 04	2-15-91			
RC91SP3	14 16/02 43	6-11-91	15.610	38.330	0.70848
RC91SP4	14 45/04 04	6-12-91			0.70858
RC91SP5	09 03/15 58	6-13-91	15.680	38.636	0.70771
RC91SP6	10 00/17 04	6-13-91			0.71134
RC91SP7	11 09/15 54	6-14-91			
RC91SP8	12 23/16 19	6-14-91			0.70711
RC91SP9	12 26/16 29	6-14-91			
RC91SP10	14 05/16 17	6-15-91			

Sample ID	Lat./Long.*	Date Collected	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	$^{87}Sr/^{86}Sr$
RC91ST1	17 12/04 38	2-15-91			
RC91ST2	11 15/03 24	6-11-91			0.70729
RC91ST3	06 33/09 28	6-12-91			
RC91ST4	11 39/09 05	6-12-91			0.70758
RC91ST5	09 50/15 40	6-13-91			
RC91ST6	09 55/17 05	6-13-91			
RC91ST7	10 33/16 06	6-13-91			
RC91ST8	09 13/14 14	6-13-91			
RC91ST9	11 14/16 03	6-14-91			
SEE-161		2-14-91	15.781	39.257	0.70981
SEE-630		2-14-91			
SEE-647		2-14-91	15.759	39.153	0.70957
91-124	13 48/11 27	6-15-91			

* Numbers represent minutes and seconds for latitude and longitude, respectively. The degree values are the same for all samples. Latitude is 41° and longitude is 117°.

VITA

Barrett Arthur Cieutat

Candidate for the Degree of

Master of Science

Thesis: THE USE OF ISOTOPES IN DETERMINING ORIGIN AND FLOW PATHS OF GROUND WATER IN THE KELLY CREEK BASIN, NORTH-CENTRAL NEVADA

Major Field: Geology

Biographical:

Personal Data: Born in New Orleans, Louisiana, January 18, 1967, the son of Roland and Grace Cieutat.

Education: Graduated from Benjamin Franklin Senior High School, New Orleans, Louisiana, in May 1984; received Bachelor of Science degree in Geology from Southern Methodist University in May, 1988; completed requirements for the Master of Science degree at Oklahoma State University in July, 1992.

Professional Experience: Student Appointment, United States Geological Survey (USGS), Branch of Geochemistry, August, 1989, to present; Teaching Assistant, Department of Geology, Oklahoma State University, August, 1989, to May, 1991; NAGT-Geologist, USGS, Branch of Geochemistry, June, 1988, to September, 1988; Temporary Appointment, USGS, Branch of Geochemistry, January, 1989, to August, 1989; Geology Tutor, S.M.U. Tutorial Service, Southern Methodist University, August, 1987, to May, 1988; Research Assistant, Department of Geology, Southern Methodist University, August, 1987, to May, 1988.