EVALUATION OF POTENTIAL GEOLOGIC SOURCES OF NITRATE CONTAMINATION IN GROUND WATER, CEDAR VALLEY, IRON COUNTY, UTAH WITH EMPHASIS ON THE ENOCH AREA

by

Mike Lowe and Janae Wallace

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UTAH DEPARTMENT OF NATURAL RESOURCES
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TABLE OF CONTENTS

FIGURES

TABLES

PLATE

EVALUATION OF POTENTIAL GEOLOGIC SOURCES OF NITRATE CONTAMINATION IN GROUND WATER, CEDAR VALLEY, IRON COUNTY, UTAH WITH EMPHASIS ON THE ENOCH AREA

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ABSTRACT

Cedar Valley in southwestern Utah is experiencing an increase in residential development, much of which uses septic tank soil-absorption systems for wastewater disposal. Most of this development is taking place on unconsolidated basin-fill deposits, the principal aquifer providing almost all of Cedar Valley's drinking-water supply. Local government officials in Iron County have expressed concern about the potential impact of development on ground-water quality, but they are also concerned that there may be unidentified natural sources contributing to elevated nitrate levels near Enoch. Therefore, the Utah Geological Survey investigated the nature and extent of nitrate contamination in Cedar Valley, and preliminarily evaluated geologic units to determine if sources of geologic nitrogen might exist; the Enoch area became the focus of this investigation. Geologic nitrogen is defined as nitrogen contained in rock or sediment.

We analyzed several geologic units in the Enoch area for nitrogen content. Four of nine rock and sediment samples tested did not contain geologic nitrogen, and three contained low concentrations of nitrogen (40-60 ppm). However, two samples from the Cretaceous Straight Cliffs Formation in Fiddlers Canyon, upgradient from Enoch, showed moderate concentrations of nitrogen. An organic-rich carbonaceous siltstone and a fine-grained calcareous sandstone have nitrogen concentrations of 530 and 670 parts per million, respectively, suggesting that some strata in the Straight Cliffs Formation contain nitrogen that could oxidize to nitrate and leach into ground water.

Previous workers identified high nitrate concentrations in ground water in the Enoch area. For instance, water samples from 101 water wells were analyzed for nitrate during 1979-81 in the Enoch area. Water samples from about 30 of the wells were tested seasonally, some up to 19 different times per year. The nitrate values remained fairly constant and did not fluctuate greatly with the seasons. The range in nitrate concentration for ground water in the 101 wells sampled is 0.06 to 57.4 mg/L, with an average of 7.59 mg/L. Twenty-one wells (21%) yielded water samples that exceed the ground-water-quality (health) standard of 10 mg/L. An additional 18 wells (18%) yielded water samples with nitrate concentrations ranging between 5 and 10 mg/L.

Depths of the 101 sampled water wells range from 116 to 800 (two wells at 800) feet (35 244 m). Twenty-eight wells have depths ranging between 116 and 300 feet (35-91 m), and 32 wells are deeper than 300 feet (91 m). No correlation exists between well depth and nitrate concentration; we would generally expect such a correlation if the source of the nitrate was entirely from near-ground-surface sources such as septic-tank systems. For example, ground water from one 700-foot well has a nitrate concentration of 10.42 mg/L, and ground water from shallower wells with depths of 240 and 252 feet have nitrate concentrations of 2.2 and 2.7 mg/L, respectively.

During June 1999, we resampled 21 of the water wells originally tested in 1979-81 to evaluate any trends in nitrate concentration over time. Nitrate concentrations from the 1999 testing range from 1 to 23.1 mg/L, with an average of 8.1 mg/L and median of 6.3 mg/L. Nitrate concentrations in water samples from five wells (21%) exceed the ground-water-quality standard of 10 mg/L. More than half, or 13, of the wells yielded water samples that maintained concentrations similar to samples taken between 1979 and 1981. Nitrate concentrations in water samples from five wells dropped considerably; four of these wells previously exceeded the ground-water standard in 1979-81, but were below it in 1999. Three other wells yielded water samples that have nitrate concentrations of more than twice the ground-water-quality standard.

In general, overall nitrate concentration in water wells in the Enoch area in 1999 remains consistent with data collected 20 years earlier, despite Enoch's conversion to a sanitary sewer system in 1995. The area maintains a relatively elevated background concentration of nitrate, especially compared to similar rural areas in other Utah basins that typically have average background nitrate concentrations around 2 mg/L. In addition to human activity/land-use practice (such as the use of septic-tank systems and residential and agricultural fertilizer application) as a common source of high ni-

trate, we consider natural geologic nitrate to be a viable explanation for the anomalously high concentration of nitrate in the Enoch area. Evidence supporting this conclusion includes: (1) the overall negligible seasonal changes in nitrate concentrations, (2) high nitrate concentrations in ground water tapped by both deep and shallow wells, (3) ground water having a high nitrate concentration in a well drilled in 1999 on the Fiddlers Canyon alluvial fan upgradient from any septic-tank systems, and (4) the lack of significant change in nitrate concentrations since the establishment of a sanitary sewer in the Enoch area in 1995. Some rock layers in the Straight Cliffs Formation are likely one source of this geologic nitrogen. Other areas in Cedar Valley that do not have these same rock units in their drainage basins have lower background levels of nitrate in ground water, which further supports our conclusion that geologic nitrogen is a possible source of nitrate in ground water in the Enoch area. However, nitrogen associated with human activities such as wastewater disposal using septic-tank systems and domestic and agricultural fertilizer application is also likely contributing to nitrate concentrations in ground water in the Enoch area.

INTRODUCTION

Cedar Valley, Iron County (figure 1), is experiencing an increase in residential development. Most of this development uses septic tank soil-absorption systems for wastewater disposal and is situated on unconsolidated deposits of the principal basin-fill aquifer. Ground water provides almost all of the drinking-water supply in Cedar Valley. Preservation of ground-water quality and the potential for ground-water-quality degradation are critical issues which should be considered in determining the extent and nature of future development in Cedar Valley. Local government officials in Iron County have expressed concern about the potential impact development may have on ground-water quality, but they are also concerned that natural sources of ground-water-quality degradation may exist, particularly nitrate, and have not been identified. These public officials would like to know the source and extent of elevated nitrate levels in ground water near Enoch. Although septic-tank systems are recognized as a potential source of nitrate, we evaluated geologic units in the Enoch area to determine if natural sources of nitrate also exist.

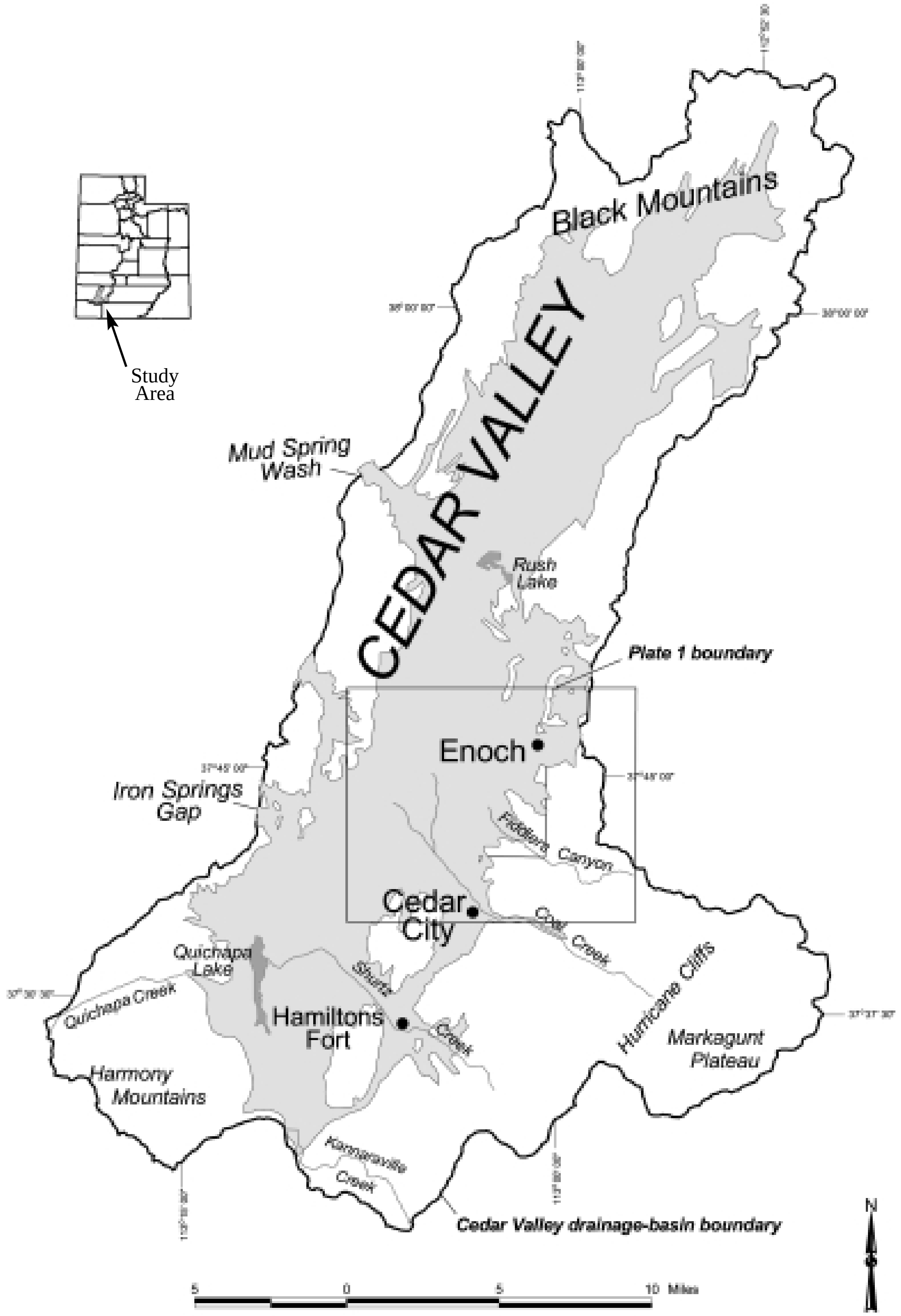

Figure 1. *Location map of Cedar Valley, Iron County, Utah (showing Enoch area study boundary). Shaded area represents extent of basin-fill deposits.*

Purpose and Scope

The purpose of this investigation is to: (1) identify rock units and unconsolidated deposits in Cedar Valley which may contain geologic nitrogen, (2) evaluate the concentration of nitrate in ground water, (3) evaluate the concentration of nitrogen in selected rocks and unconsolidated deposits, and (4) assess the likelihood that nitrogen-rich geologic materials are contributing to elevated levels of nitrate in ground water in the Enoch area. Geologic nitrogen is defined as nitrogen contained in rock or sediment (Holloway and others, 1998). Geologic nitrogen can take the form of either ammonium substituting for potassium in minerals such as muscovite, or relict organic matter unaltered by geologic processes such as lithification and diagenesis. Geologic nitrogen is generally associated with sedimentary rock (Stevenson, 1962).

The scope of work included: (1) a review of literature on the geology of Cedar Valley, (2) a review of literature on naturally occurring nitrogen compounds which might contribute to nitrate in ground water, (3) collection of ground-water samples, (4) analyses of water-quality data from previous investigations and this study, (5) collection of rock and soil samples in the field and from water-well cuttings, (6) laboratory analysis of samples for geologic nitrogen content (appendix A), and (7) preparation of this report. This study focuses on the Enoch area (figure 1), where elevated nitrate levels in ground water have been documented, and on Fiddlers Canyon, the source of most ground-water recharge to the Enoch area.

Well Numbering System

The numbering system for wells in this study is based on the Federal Government cadastral land-survey system that divides Utah into four quadrants (A-D) separated by the Salt Lake Base Line and Meridian (figure 2). The study area is entirely within the southwestern quadrant (C). The wells are numbered with this quadrant letter C, followed by township and range, enclosed in parentheses. The next set of characters indicates the section, quarter section, quarter-quarter section, and quarter-quarter-quarter section, designated by the letters a through d, indicating the northeastern, northwestern, southwestern, and southeastern quadrants, respectively. A number after the hyphen corresponds to an individual well within a quarter-quarter-quarter section. For example, the well (C-36-12)2adb-1 would be the first well in the northwestern quarter of the southeastern quarter of the northeastern quarter of section 2, Township 36 South, Range 12 West (NW$^1/_4$SE$^1/_4$NE$^1/_4$ section 2, T. 36 S., R. 12 W.).

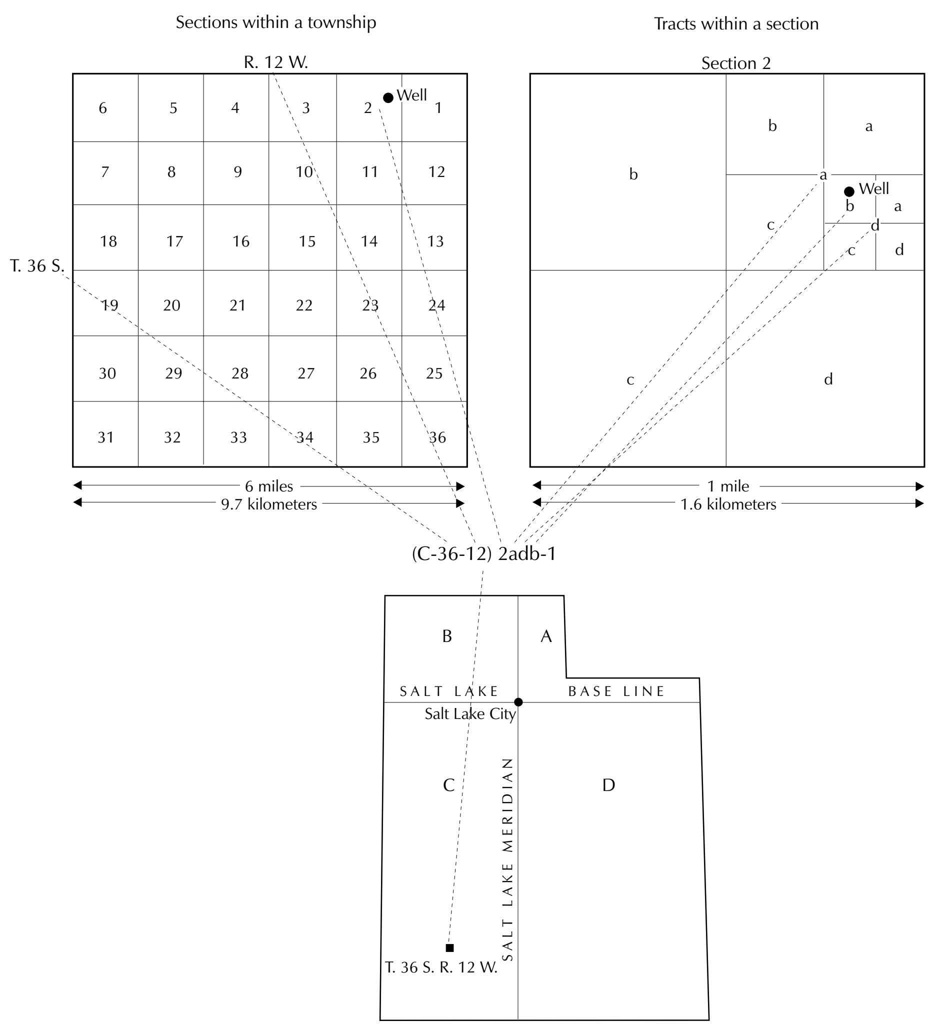

Figure 2. *Numbering system for wells in Utah (see text for additional explanation).*

Location and Geography

Cedar Valley is in eastern Iron County, southwestern Utah, between 38°07'15" and 37°32'15" north latitude and 113°23'15" and 112°49' west longitude (figure 1). It is a northeast-southwest-trending, elongate valley bordered by the Black Mountains to the north, the Markagunt Plateau to the east, low-lying mountains and hills to the west, and the Harmony Mountains to the southwest. Cedar Valley is approximately 32 miles (51 km) long and ranges from 8 miles (13 km) wide at its northern boundary to less than 1 mile (1.6 km) wide in the south. The floor of Cedar Valley covers 170 square miles (440 km^2); its drainage basin encompasses more than 580 square miles (1,502 km^2). Elevations range from 11,307 feet (3,446 m) at Brian Head in the Markagunt Plateau to about 5,350 feet (1,631 m) at the outlet at Mud Springs Wash in the northwest part of the valley.

Coal Creek, the principal perennial stream in Cedar Valley, flows westward from the Markagunt Plateau and has deposited a large alluvial fan in the Cedar City area (Bjorklund and others, 1978). Shirts Creek, formerly known as Shurtz Creek, a smaller perennial stream flowing westward from the Markagunt Plateau, enters Cedar Valley near Hamiltons Fort. The creek in Fiddlers Canyon, one of the larger intermittent and ephemeral streams flowing westward from the Markagunt Plateau, enters Cedar Valley between Cedar City and Enoch. Quichapa Creek is a perennial stream flowing northeastward into the valley from the Harmony Mountains. Surface water flows westward out of Cedar Valley via Mud Spring Wash and Iron Springs Gap only during rare flash floods following very heavy local precipitation (Bjorklund and others, 1978). Some spring runoff accumulates in Quichapa and Rush Lakes, which are shallow playa lakes.

Enoch (figures 1 and 3) is 6 miles (10 km) north of Cedar City, just southwest of the southwest end of Parowan Valley and northwest of the mouth of Fiddlers Canyon. The valley floor in the Enoch area slopes gently to the southwest. The Enoch area covers about 30 square miles (80 km^2) with elevations ranging from about 6,200 feet (1,900 m) near the mouth of Fiddlers Canyon to about 5,490 feet (1,673 m) near Mid Valley Estates subdivision.

Population and Land Use

Iron County has the fourth highest county growth rate in the state; its population increased from 17,349 in 1980 to 30,477 in 1998 (Utah Division of Water Rights, 1980, 1995; Demographic and Economic Analysis Section, 1999). Population is projected to increase by 2.6 percent annually over the next 22 years; by 2020 the population of Iron County is expected to be over 54,149 (Demographic and Economic Analysis Section, 1998). The 2000 estimated Census population for Enoch is 3,256 (Utah League of Cities and Towns, 2000).

Government and trade have provided employment in Iron County for more than a decade; these sectors are expected continue to provide the most jobs, but employment in the service industry is expected to increase significantly (Utah Division of Water Resources, 1995, table 4-4). Although employment in agriculture is growing at a much lower rate, agricultural commodity production, mostly beef, dairy, and irrigated crops, will likely continue to be an important part of Cedar Valley's economy (Utah Division of Water Resources, 1995). Enoch is primarily a residential area, which used septic systems, outhouses, and other types of onsite facilities for wastewater disposal from the 1800s until 1995, when the town switched to a sanitary sewer system for much of the development.

Climate

Cedar Valley's climate is characterized by large daily temperature variations, moderately cold winters, and warm, dry summers. Temperatures range from a maximum of about 100°F (38°C) to a minimum of about 0°F (-18°C); the maximum daily temperature variation is greatest in the summer when fluctuations can be as much as 40°F (about 22°C) (Ashcroft and others, 1992). The mean annual temperature at the Cedar City airport was 49°F (9°C) from 1961 to 1990 (Utah Division of Water Resources, 1995). The growing season (the number of consecutive frost-free days) in Cedar Valley averages 135 days (Ascroft and others, 1992; Utah Division of Water Resources, 1995).

Figure 3. *Location of the Enoch study area, Cedar Valley, Iron County, Utah (view is to the east toward Fiddlers Canyon).*

The Markagunt Plateau receives between 16 and 40 inches (41-102 cm) of precipitation annually (Utah Division of Water Resources, 1995), mostly as snow during the winter. Annual precipitation in Cedar Valley ranges from about 8 to 14 inches (20-36 cm) (Bjorklund and others, 1978). At the Cedar City airport, mean annual precipitation was 11.5 inches (29.2 cm) and mean annual evapotranspiration was 34.4 inches (87.4 cm) from 1961 to 1990 (Utah Division of Water Resources, 1995). Most precipitation is generated in winter and spring by humid air masses moving southeastward from the north Pacific (Bjorklund and others, 1978). Snow is common in Cedar Valley from December through March, but snowstorms are not uncommon during April and even May (Bjorklund and others, 1978).

PREVIOUS INVESTIGATIONS

Early reconnaissance studies of the geology and physiography of southwestern Utah, including descriptions of the Cedar Valley area, were conducted by Gilbert (1875), Howell (1875), Powell (1879), and Dutton (1880). Research on the coal and ore deposits of the Cedar Valley region early in the 1900s was conducted by Lee (1907), Leith and Harder (1908), and Richardson (1909). Figure 4 shows the sources of modern geologic mapping investigations which were used for this study. Averitt (1962, 1967), Averitt and Threet (1973), Rowley (1975, 1976), Mackin and others (1976), Mackin and Rowley (1976), Rowley and Threet (1976), Maldonado and Moore (1993), Maldonado and Williams (1993a,

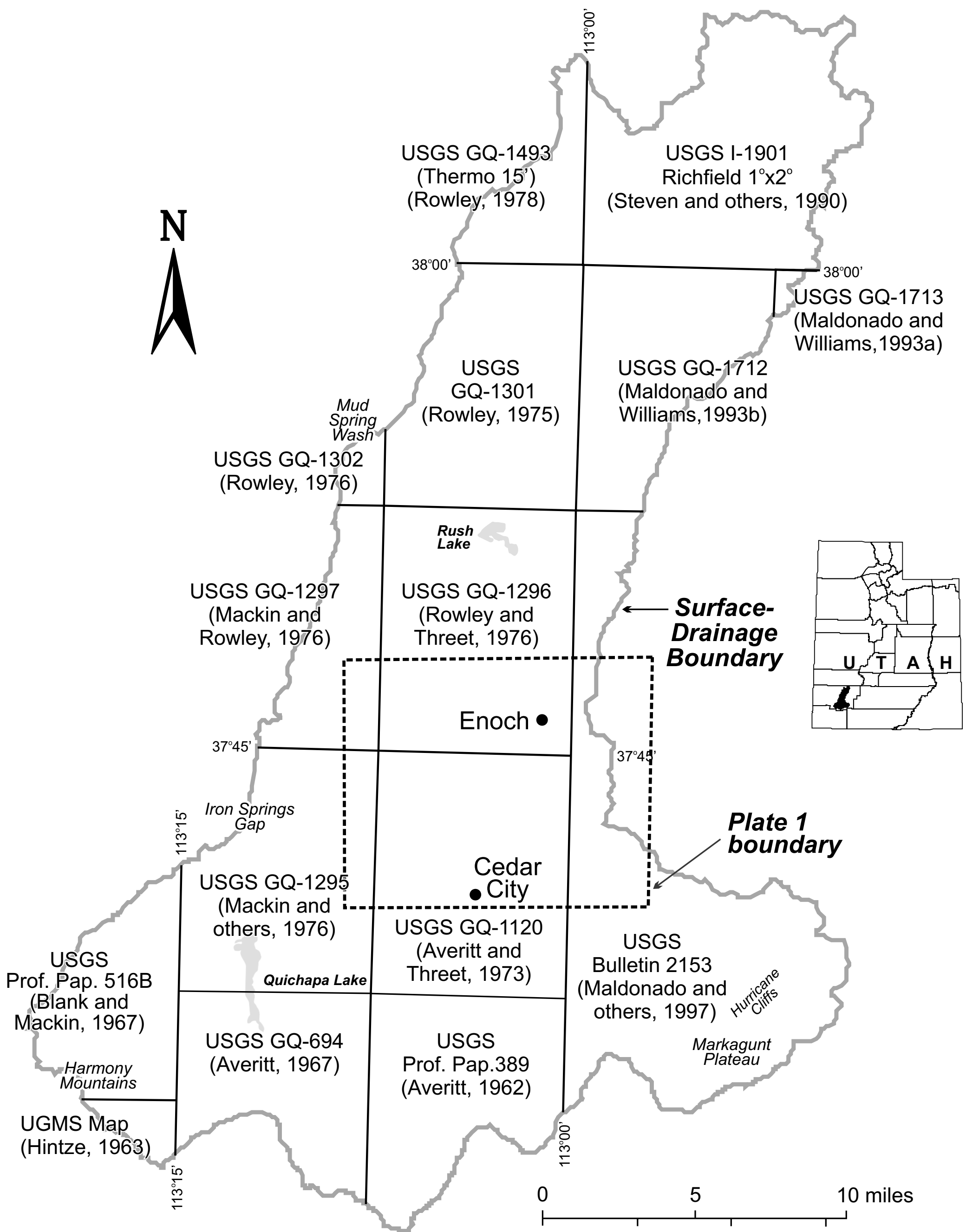

Figure 4. *Sources of geologic mapping in Cedar Valley, Iron County, Utah, used for this study.*

b), and Moore and Nealey (1993) produced 7.5' geologic quadrangle maps of the Cedar Valley area; the geologic maps of the Cedar City Northwest and Kanaraville quadrangles by Mackin and others (1976) and Averitt (1967), respectively, are particularly relevant to our study. Rowley (1978) mapped the geology of the Thermo 15' quadrangle. Steven and others (1990) mapped the geology of the Richfield 1° x 2° quadrangle which includes the northern part of the Cedar Valley area. Averitt (1962), Threet (1963), Stewart and others (1972a, b), and Maldonado and others (1997) studied the structure of the Cedar Valley region. Huntington and Goldthwait (1904), Mackin (1960), Averitt (1962), Hamblin (1970, 1984), Rowley and others (1978), Anderson and Mehnert (1979), Anderson (1980), and Anderson and Christenson (1989) studied the Hurricane fault zone and discussed its significance as a possible boundary between the Basin and Range and Colorado Plateau physiographic provinces. Blank and Mackin (1967) made a geologic interpretation of an aeromagnetic survey of the southwest part of the Cedar Valley area. Eppinger and others (1990) assessed the mineral resources of the Cedar City 1° x 2° quadrangle.

Meinzer (1911) conducted an early reconnaissance investigation of water resources in western Utah, including Cedar Valley which he called Rush Lake Valley. Thomas and Taylor (1946) completed the first comprehensive investigation of ground-water conditions in Cedar Valley. Subsequent ground-water investigations were conducted by Thomas and others (1952) and Sandberg (1963, 1966). Barnett and Mayo (1966) made recommendations regarding ground water management and warned of a potential water-resources crisis in Cedar Valley. Bjorklund and others (1977, 1978) conducted the most recently completed study of ground-water conditions in Cedar Valley. Since then, the Utah Division of Water Resources, the Utah Division of Water Quality, and the U.S. Geological Survey have collected ground-water data periodically as part of an established monitoring network. Previous work on recommended septic-tank-system density/lot size in Cedar Valley includes Wallace and Lowe (1998, 1999), Lowe and Wallace (1999a,b), and Lowe and others (2000). Wallace and Lowe (2000) evaluated the potential contribution of geologic nitrogen to nitrate in ground water in the Enoch area.

GEOLOGIC SETTING OF CEDAR VALLEY DRAINAGE BASIN

The Cedar Valley drainage basin lies in the transition zone between the Basin and Range and Colorado Plateau physiographic provinces (Stokes, 1977). The Hurricane fault zone (figure 5), which probably first formed in the Pliocene, is generally considered to be the boundary between the provinces (for instance, Dutton, 1880). The general location of the Hurricane fault zone is marked by the sheer Hurricane Cliffs which are up to 2,000 feet (610 m) high (Hamblin, 1970). The width of the fault zone, located at the base of the cliffs, is quite variable, but is locally up to several miles wide (Averitt, 1962). South of Cedar City (in the Cedar Mountain quadrangle, for example), the Hurricane fault zone is about 3 miles (5 km) wide (Averitt, 1962). Although the Hurricane fault zone has evidence of Holocene activity and is considered seismically active and potentially capable of producing future surface-faulting earthquakes, most movement occurred during the Pliocene and Pleistocene (Pearthree and others, 1998). Total vertical displacement along the Hurricane fault zone is estimated to be between 1,500 and 4,000 feet (457 and 1,220 m) (Kurie, 1966; Anderson and Mehnert, 1979).

The Markagunt Plateau, east of the Hurricane Cliffs, has some features characteristic of the Colorado Plateau physiographic province, such as high elevation and relief dominated by gently dipping sedimentary rocks that are locally disrupted by folds and faults. However, the aligned volcanic cones and prevalent northeast-trending block faults of the Markagunt Plateau are more typical of the Basin and Range physiographic province. Geomorphic features of the Markagunt Plateau include: (1) narrow, predominantly westward sloping, V-shaped valleys, (2) steep-sided sharp-crested ridges, (3) structurally controlled drainage alignments, (4) elongated closed basins, and (5) hillside trenches or depressions (Anderson and Christenson, 1989).

Cedar Valley to the west of the Hurricane Cliffs is characterized by geomorphic features typical of other closed basins in the Basin and Range physiographic province. The basin margins consist of broad alluvial-fan slopes that grade basinward into slightly undulating plains, the lowest depressions of which contain lakes, swamps, and dry alkali flats (Meinzer, 1911). A low divide, created by the alluvial fan deposited by Coal Creek, separates Cedar Valley into two subbasins. The south basin drains into saline Quichapa Lake; the north basin partly drains into Rush Lake, and water from Coal Creek may also drain to depressions farther south (Meinzer, 1911).

Stratigraphy

Introduction

Stratigraphic units in the Cedar Valley area range from Triassic to Quaternary in age (figure 6). Consolidated rocks have a maximum combined thickness of more than 16,000 feet (4,900 m) (Bjorklund and others, 1978). Unconsolidated deposits are at least 1,000 feet (300 m) thick in Cedar Valley (Bjorklund and others, 1977, table 4). The unit descriptions provided below are modified from the referenced previous work. Figures 5 and 6 present the generalized stratigraphy of the Cedar Valley drainage. Below we provide a more detailed description of stratigraphic units in the drainage basin because, based on our literature search, geologic nitrogen is more likely to be associated with certain rock types and/or depositional environments than with others; the detailed descriptions provided the basis for determining from which geologic units to collect rock and/or sediment samples for nitrogen analysis.

Triassic

Moenkopi Formation: The Early Triassic Moenkopi Formation disconformably overlies the Kaibab Formation (not exposed in area shown on figure 5) and is made up of six members in the Cedar Valley area, including, from oldest to youngest, the Timpoweap Member, lower red member, Virgin Limestone Member, middle red member, Shnabkaib Member, and upper red member (Hintze, 1988). The Tim-

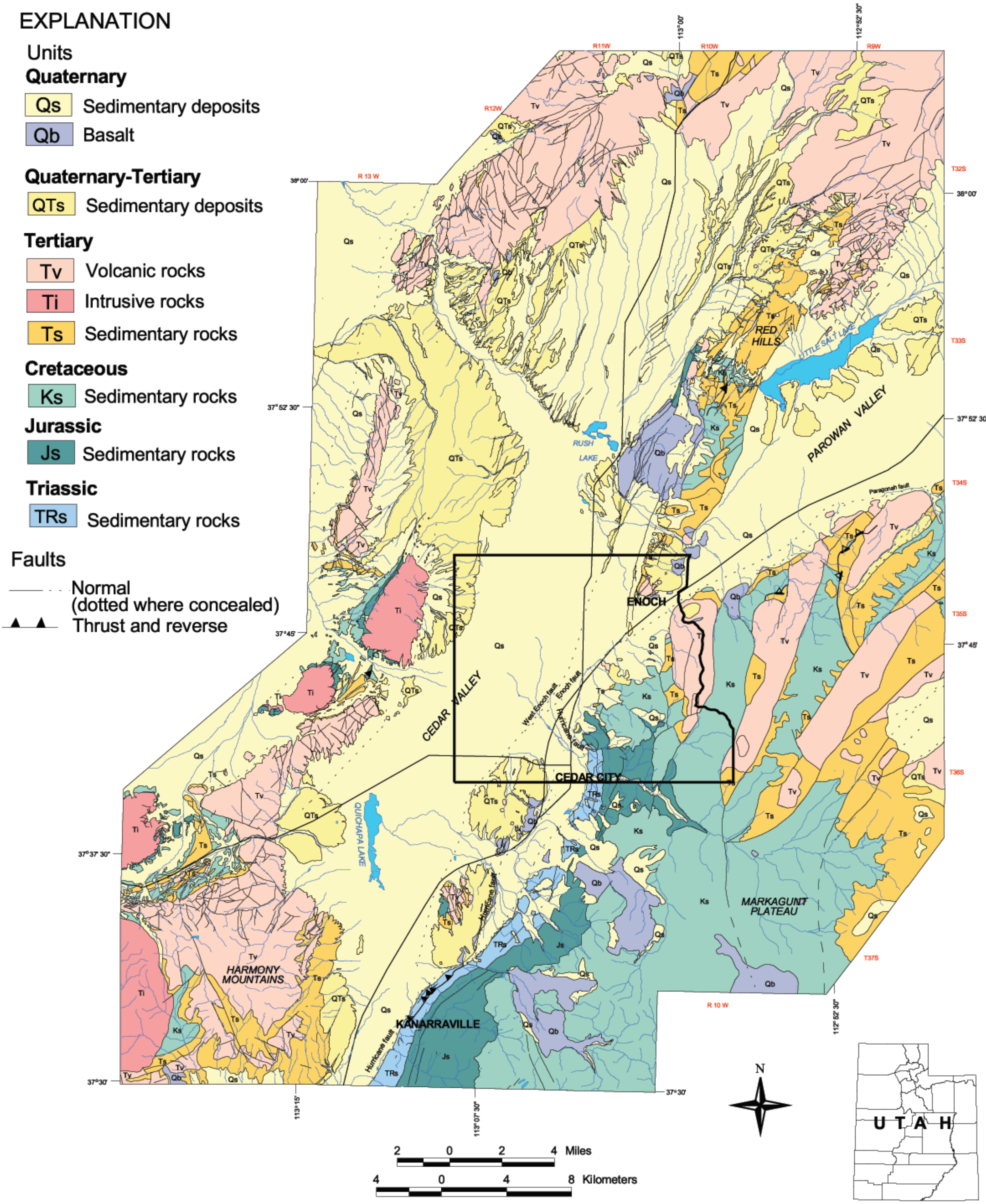

Figure 5. *Simplified geologic map of Cedar Valley, Iron County, Utah. See figure 4 for sources of mapping.*

Age (Ma)	Period	Map Symbol and Unit Name	Description	Approximate Thickness in feet (m)
	QUATERNARY	Qs Sedimentary deposits	Interbedded gravel, sand, silt and clay.	0 - 150+ (0 - 45)
		Qb Basalt	Flows and small cinder cones.	0 - 330+ (0 - 100)
1.8	QUATERNARY-TERTIARY	QTs Sedimentary deposits	Interbedded gravel, sand, silt and clay.	0 - 1,330 (0 - 405)
	TERTIARY	Ti Intrusive rocks	Quartz monzonite intrusions of the "iron axis"	
		Tv Volcanic rocks	Interbedded ash-flow tuff, volcanic breccia, flows, and related sedimentary deposits.	0 - 4,000 (0 - 1,200)
		TKs Sedimentary rocks	Interbedded mudstone, siltstone, sandstone, conglomerate, and limestone.	2,190 - 2,320 (665 - 705)
65	CRETACEOUS	Ks Sedimentary rocks	Interbedded sandstone, mudstone, conglomerate, and coal.	2,700 - 3,600 (825 - 1,100)
144	JURASSIC	Js Sedimentary rocks	Interbedded sandstone, siltstone, mudstone, and limestone.	3,900 - 5,150 (1,200 - 1,575)
206	TRIASSIC	T̄Rs Sedimentary rocks	Interbedded sandstone, siltstone, mudstone, gypsiferous mudstone, and minor conglomerate.	2,100 - 2,400 (640 - 730)

C:Cedar Valley/Nitrate Figure 6

Figure 6. *Generalized stratigraphic column for Cedar Valley drainage basin. Units correspond to those on figure 5 (modified from Hurlow, in preparation).*

poweap Member consists of fossiliferous, yellowish-gray limestone and shaly limestone (Averitt, 1962, 1967; Averitt and Threet, 1973). The slope-forming lower red member consists of red-brown siltstone and mudstone with some thin gypsum layers (Averitt, 1962, 1967; Averitt and Threet, 1973). The ridge-forming Virgin Limestone Member consists of fine-grained limestone and silty shale with a basal fossiliferous unit (Averitt, 1962, 1967; Averitt and Threet, 1973). The middle red member consists of red-brown siltstone and mudstone with minor beds of gray-white gypsum (Averitt, 1962). The Shnabkaib Member consists of light gray, olive-gray, and red-brown siltstone and mudstone (Averitt, 1962). The upper red member consists of red-brown and light brown siltstone and mudstone intercalated with gray-white gypsum (Averitt, 1962). The Moenkopi Formation was deposited in a shallow water (both marine [limestone units] and nonmarine [siltstone and mudstone units]) environment (Averitt, 1962).

Chinle Formation: The Late Triassic Chinle Formation disconformably overlies the Moenkopi Formation (Averitt, 1962) and, in the Cedar Valley area, consists of the basal Shinarump Conglomerate Member and the upper Petrified Forest Member (Hintze, 1988). The ridge-forming Shinarump Conglomerate Member consists of light gray, yellowish-gray, and greenish-gray, fine- to coarse-grained, cross-bedded sandstone with some chert-pebble conglomerate (Averitt, 1962, 1967; Averitt and Threet, 1973). The slope-forming Petrified Forest Member consists of reddish brown and grayish-red mudstone and siltstone (Averitt, 1962, 1967; Averitt and Threet, 1973). The Chinle Formation was deposited in lakes and fluvial channels and flood plains (Stewart and others, 1972a).

Jurassic

Moenave Formation: The Early Jurassic Moenave Formation unconformably overlies the Chinle Formation and, in the Cedar Valley area, consists of the lower Dinosaur Canyon Member and upper Springdale Sandstone Member (Hintze, 1988). The slope-forming Dinosaur Canyon Member consists of red-brown siltstone and mudstone (Averitt, 1962, 1967; Averitt and Threet, 1973). The ridge-forming Springdale Sandstone Member consists of reddish- to purplish-brown, fine- to medium-grained, massive sandstone containing some cross-bedding (Averitt, 1962, 1967; Averitt and Threet, 1973). The Moenave Formation was deposited in fluvial channels and flood plains, lakes, sabkhas, and eolian sand dunes (Clemmensen and others, 1989).

Kayenta Formation: The Early Jurassic Kayenta Formation conformably overlies the Moenave Formation and, in the Cedar Valley area, includes two distinct mappable members separated by a tongue of Navajo Sandstone (Averitt, 1962). These stratigraphic units are the lower member, the Shurtz Sandstone Tongue of the Navajo Sandstone, and the Cedar City Tongue (Hintze, 1988). The slope-forming lower member consists of reddish-brown mudstone and silty mudstone and light gray, light brown, and reddish-orange siltstone (Averitt, 1962, 1967; Averitt and Threet, 1973). The ridge-forming Shurtz Sandstone Tongue of the Navajo Sandstone, which forms the crest of Red Hill north of Cedar Canyon, consists of reddish-orange, medium-grained, cross bedded sandstone (Averitt, 1962; Averitt and Threet, 1973). The Cedar City Tongue consists of reddish-brown mudstone and light gray to reddish-orange siltstone (Averitt, 1962; Averitt and Threet, 1973); this nonresistant unit forms a stream-trapping strike valley on both the north and south sides of Cedar Canyon. The Kayenta Formation was deposited in a shallow-water fluvial environment (Averitt, 1962; Luttrell, 1986).

Navajo Sandstone: The massive-cliff-forming Early Jurassic Navajo Sandstone conformably overlies the Kayenta Formation and consists of a moderate reddish-orange, fine- to medium grained sandstone with prominent large-scale cross-bedding (Averitt, 1962, 1967; Averitt and Threet, 1973) . The well-rounded nature of the sand grains and cross-bedding are typical of eolian dunal deposits; in some areas the Navajo Sandstone contains interdunal limestone deposits (Doelling and Davis, 1989).

Carmel Formation: The Middle Jurassic Carmel Formation disconformably overlies the Navajo Sandstone (Averitt, 1962) and is made up of four members in the Cedar Valley area, including, from oldest to youngest, the Co-op Creek Limestone Member, Crystal Creek Member, Paria River Member, and Winsor Member (Hintze, 1988). The Co-op Creek Limestone Member (limestone member of Averitt [1967] and Averitt and Threet [1973]) consists of locally fossiliferous, light gray, thin-bedded, shaly limestone. The Crystal Creek Member (banded member of Averitt [1967] and Averitt and Threet [1973]) consists of red-brown sandstone, siltstone, and mudstone containing thin beds of gypsum. The Paria River Member (gypsiferous member of Averitt [1967] and Averitt and Threet [1973]) consists of mostly massive gypsum with thin-bedded limestone near the top, which forms a break in the slope formed by the lower two members of the Carmel Formation. The slope-forming Winsor Member consists of banded light gray to red-brown sandstone and mudstone (Averitt, 1967; Averitt and Threet, 1973). The Carmel Formation has a maximum thickness of about 1,300 feet (400 m), but exhibits a marked east-west variability in thickness and facies types (Averitt, 1962; Hintze, 1988). The Carmel Formation was deposited in shallow marine (limestone and sandstone) and marginal marine (gypsum evaporite beds) environments (Hintze, 1988; Doelling and Davis, 1989).

Cretaceous

Dakota Formation: The Carmel Formation is unconformably overlain by the lithologically heterogeneous basal beds of the mostly Late Cretaceous Dakota Formation (am Ende, 1991) (the Dakota-Tropic Formation of Averitt [1962]). The slope-forming Dakota Formation consists mostly of light to dark gray shale with some pale yellowish-orange, fine- to medium-grained sandstone beds (Averitt, 1962, 1967; Averitt and Threet, 1973). The unit locally includes conglomerate at its base and contains several coal beds, including the Upper Culver coal zone at its top (Averitt, 1962). Regionally, the Dakota Formation records fluvial environments grading upward into brackish/shallow marine environments. The lower part of the unit was deposited in fluvial environments as indicated by braided-stream, overbank flood-plain, and anastomosed stream-channel sediments (am Ende, 1991). Higher in the sequence, the formation records a marine environment characterized by lagoonal, lower shoreface, foreshore, coastal sand body, barrier-bar, and transgressive-ravinement sediments (am Ende, 1991).

Straight Cliffs Formation: The Late Cretaceous Straight Cliffs Formation overlies the Dakota Formation in the eastern part of the Cedar Valley drainage basin and consists of a lower cliff forming, fine-grained, massive sandstone and subordinate siltstone and an upper slope-forming, fine-grained, thin-bedded sandstone and siltstone (Averitt and Threet, 1973). The Straight Cliffs Formation contains shale and marl at its base, four or five layers of up to 6-foot-thick (2 m) oyster beds distributed through the entire formation, and thin, discontinuous coal beds and carbonaceous organic-rich siltstone layers in the upper part of the formation (Averitt, 1962). The Straight Cliffs Formation was deposited in a variety of environments including fluvial, swamp, and coastal flood plain (Peterson, 1969), but primarily represents nearshore marine deposition (Doelling and Graham, 1972).

Wahweap Sandstone: The Late Cretaceous Wahweap Sandstone conformably overlies the Straight Cliffs Formation in the eastern part of the Cedar Valley drainage basin; these two units are similar, especially near their contact, and are commonly lumped together as an undivided map unit. The slope-forming Wahweap, in the Cedar City area, consists of shale and siltstone with minor sandstone (Averitt and Threet, 1973). Sandstone is most prevalent in the lower part of the formation (Averitt, 1962). The Wahweap Sandstone was deposited in nearshore marine and fluvial channel and flood-plain environments (Doelling and Graham, 1972).

Kaiparowits Formation: The Late Cretaceous Kaiparowits Formation overlies the Wahweap Sandstone in the eastern part of the Cedar Valley drainage basin and consists predominantly of very light gray to pale yellowish-gray, friable, well-sorted, fine- to medium-grained sandstone with minor interbeds of mudstone (Moore and Nealey, 1993). The upper part of the mostly cliff forming formation is mainly cherty, argillaceous, yellowish-orange "salt-and-pepper" sandstone (Moore and Nealey, 1993). The Kaiparowits Formation was deposited in fluvial channels and flood plains on the western shore of the Western Interior Seaway (Roberts and Kirschbaum, 1995).

Iron Springs Formation: The Late (?) Cretaceous Iron Springs Formation unconformably overlies the Carmel Formation in the western part of the Cedar Valley drainage basin (Maldonado and Williams, 1993a), and correlates with the Late Cretaceous formations exposed in the eastern part of the drainage basin (Hintze, 1988). The cliff-forming Iron Springs Formation consists predominantly of yellowish-gray, grayish-yellow, moderate yellow, and dark yellowish-orange, fine- to medium-grained, thin-bedded to massive sandstone (Maldonado and Williams, 1993a). The lower part of the unit contains some carbonaceous shale and coal, with some thin conglomerate beds and maroon shale at the base; the upper part contains several thin, interbedded, light gray siltstone beds near the top (Maldonado and Williams, 1993a). The Iron Springs Formation is likely fluvial in origin (Fillmore, 1991; Maldonado and Williams, 1993a).

Tertiary

Introduction: Tertiary rocks include fluvial, alluvial-fan, volcaniclastic, and volcanic units, some of which are localized and unnamed. The stratigraphic relationships between the units are complex and commonly difficult to differentiate; hence, some are lumped together as mappable units. The major Tertiary units are described below.

Grand Castle Formation: The Paleocene Grand Castle Formation unconformably overlies the Cretaceous units and consists of upper and lower boulder- and pebble-conglomerate members separated by very fine-grained to fine-grained sublitharenite and litharenite (Goldstrand and Mullett, 1997). The Grand Castle Formation was deposited in a braided fluvial environment (Goldstrand and Mullett, 1997).

Claron Formation: The Paleocene-Oligocene Claron Formation (Rowley and Threet, 1976; Hintze, 1988) is a cliff-forming unit which consists mainly of pale red to white, thin- to thick bedded sandstone, shale, and limestone with some pebble conglomerate; the upper part of the formation includes volcanic detritus (Rowley and Threet, 1976). The Claron Formation was mostly deposited in a lacustrine environment (Doelling and Graham, 1972), but also records some fluvial deposition (Rowley and Threet, 1976).

Brian Head Formation: The Oligocene Brian Head Formation is poorly resistant and mapped separately from the uppermost part of the Claron Formation of Anderson and Rowley (1975) due to an abundance of volcaniclastic material (Sable and Maldonado, 1997). The unit consists dominantly of yellowish-gray and light gray, cross-bedded, tuffaceous sandstone with interbedded pebble- to boulder-size conglomerate, sandstone, and minor limestone and mudflow breccia (Maldonado and Moore, 1993).

Needles Range Group: The moderately resistant Oligocene Needles Range Group includes the Wah Wah Springs Formation, the Cottonwood Wash Tuff, and the Lund Formation (Maldonado and Moore, 1993; Maldonado and Williams, 1993a,b). All three formations are moderately welded, dacitic ash-flow tuffs (Best, Christiansen, and Blank, 1989; Maldonado and Moore, 1993; Maldonado and Williams, 1993a,b). The Wah Wah Springs Formation is grayish-orange-pink to light brownish-gray (Maldonado and Williams, 1993a). The Indian Peak caldera along the central Utah-Nevada border is the likely source area (Best and Grant, 1987; Best, Christiansen, and Blank, 1989). The Cottonwood Wash Tuff is grayish-orange-pink to light brownish-gray. Its source area likely is located between the Fortification Range of eastern Nevada and the Mountain Home Range of southwestern Utah (Best, Christiansen, and Blank, 1989). The Lund Formation is grayish-orange-pink. The White Rock caldera along the central Utah-Nevada border is the likely source area (Best and Grant, 1987; Best, Christiansen, and Blank, 1989; Best, Christiansen, Deino, and others, 1989).

Isom Formation: The Oligocene Isom Formation consists of two resistant, densely welded, trachytic ash-flow tuff units: the lower Bald Hills Tuff Member and the upper Hole-In-The-Wall Tuff Member (Mackin, 1960; Rowley, 1975,1976; Mackin and others, 1976; Mackin and Rowley, 1976; Hintze, 1988). The Bald Hills Tuff Member consists of chocolate-brown, medium brown, medium tan, medium gray, or brownish-purple crystal-poor ash-flow tuff, possibly containing lava flows (Rowley, 1975,1976; Mackin and others, 1976; Mackin and Rowley, 1976). The Hole-In-The-Wall Tuff Member consists of medium red to tan, crystal-poor ash-flow tuff containing abundant pin-size vesicles (Rowley, 1975,1976; Mackin and others, 1976; Mackin and Rowley, 1976). A caldera at the northwest edge of the Escalante Desert is the likely source of the Isom Formation tuffs (Best, Christiansen, and Blank, 1989).

Bear Valley Formation: The Oligocene or Miocene Bear Valley Formation consists of poorly resistant, olive-gray, yellow-gray, pale green and medium green, commonly cross-bedded, medium-grained tuffaceous sandstone and lesser sandy conglomerate (Rowley, 1975; Maldonado and Williams, 1993a). Anderson (1971) concluded this formation is mostly eolian in origin.

Flows of Mud Spring: The Miocene Flows of Mud Spring are resistant, dark reddish-brown or grayish-purple, flow-foliated, crystal-poor lava flows and feeder dikes (Rowley, 1976).

Quichapa Group: The Miocene Quichapa Group consists of the lower Leach Canyon Formation, the middle Condor Canyon Formation (Mackin and Rowley, 1976), and the upper Harmony Hills Tuff (Averitt, 1967; Rowley, 1978). The Leach Canyon Formation is made up of the lower Narrows Tuff Member and upper Table Butte Tuff Member (Mackin and Rowley, 1976; Hintze, 1988). The Narrows Tuff Member consists of moderately resistant, chocolate-brown, pale salmon, or light tan, moderately welded, crystal-poor ash-flow tuff containing minor volcanic fragments (Mackin and Rowley, 1976; Rowley, 1976). The Table Butte Tuff Member consists of poorly resistant, light tan, pale salmon, or white, poorly welded, crystal-poor ash-flow tuff containing abundant volcanic-lithic fragments (Mackin and

Rowley, 1976; Rowley, 1976). The Condor Canyon Formation comprises two formal members: the lower Sweet Tuff Member and upper Bauers Tuff Member (Mackin and Rowley, 1976; Rowley, 1976), locally separated by volcanic breccia (Mackin and others, 1976; Hintze, 1988), and in some places, intertonguing with the Mount Dutton Formation. The Sweet Tuff Member consists of resistant, reddish-brown to chocolate-brown, densely welded, crystal-poor ash-flow tuff containing locally abundant large vesicles (Mackin and Rowley, 1976; Rowley, 1976). The Bauers Tuff Member consists of resistant, brownish-red, densely welded, crystal-poor ash-flow tuff (Mackin and Rowley, 1976; Rowley, 1976). The Harmony Hills Tuff consists of moderately resistant, light tan, tan, pale pink, pink, grayish-orange-pink, or light red-brown, moderately welded, crystal-rich, trachytic andesitic to andesitic, ash-flow tuff (Averitt, 1967; Mackin and others, 1976; Mackin and Rowley, 1976; Rowley, 1978; Maldonado and Moore, 1993).

Mount Dutton Formation: The Miocene Mount Dutton Formation is mostly moderately resistant to nonresistant volcanic mudflow breccia consisting of angular to subrounded, dark gray, medium gray, brown, red, black, purple, yellow, and green matrix-supported, pebble- to boulder-sized clasts of dacitic to andesitic volcanic rock; the muddy to sandy matrix is light gray, pale red, grayish-orange-pink, pink, pale yellowish-brown, dusky-brown, or tan (Mackin and Rowley, 1976; Rowley, 1976, 1978; Maldonado and Williams, 1993a,b).

Horse Valley Formation: The Miocene Horse Valley Formation consists of nonresistant to resistant, mostly gray or pink, but also white, red-tan, black, purple, or brown, rhyodacitic to dacitic lava flows, volcanic mudflow breccia, plugs and minor ash-flow tuff (Rowley, 1978). The Horse Valley Formation intertongues locally with the underlying Mount Dutton Formation (Rowley, 1978).

Quartz monzonite porphyry: This unit consists of Miocene laccolithic intrusions of white to light green quartz monzonite porphyry of the Granite Mountain and Three Peaks plutons (Mackin and others, 1976; Mackin and Rowley, 1976).

Quaternary-Tertiary

Poorly consolidated sediments: Miocene, Pliocene, and Pleistocene poorly consolidated sediments consist mostly of light gray, tan or red, sandy, fine-pebble to boulder conglomerate or, less commonly, coarse-grained sandstone or colluvium (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976). These sediments mantle hilly areas around the valley margins, are likely mostly alluvial in origin, and are locally interbedded with Quaternary-Tertiary basalt lava flows (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976; Maldonado and Williams, 1993a,b). These sediments are dissected by modern streams.

Alluvium: Miocene, Pliocene, and Pleistocene alluvium consists of poorly to well-sorted, moderately to well-layered, interbedded, brown to tan gravel and sand and tan to reddish-brown silt and clay (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976). These sediments are near the valley margins in alluvial-fan and stream environments and, at some locations, contain massive debris-flow deposits consisting of unsorted pebble to boulder gravel in silty sand and clay matrix.

Basalt lava flows: Miocene, Pliocene, and Pleistocene lava flows consist of resistant, black, medium gray, or red vesicular olivine basalt with minor, poorly consolidated, black and red scoria (Rowley, 1975, 1976; Rowley and Threet, 1976).

Quaternary

Valley-bottom deposits: Pleistocene and Holocene valley-bottom deposits consist of unconsolidated clay, silt, and sand, predominantly alluvial in origin. This unit also includes deposits of a fairly extensive Pleistocene lake (Mackin and others, 1976), and calcareous, saline, gypsiferous, gray to grayish-white clay and silt exposed on the floors of Quichapa and Rush Lakes (Bjorklund and others, 1978; Maldonado and Williams, 1993a). Additionally, light orange to tan, fine-grained eolian sand dune deposits (Bjorklund and others, 1978) are present just east of Quichapa Lake (Mackin and others, 1976).

Alluvial-fan and pediment deposits: Pleistocene and Holocene alluvial-fan and pediment deposits consist predominantly of unconsolidated silt, sand, and minor pebble gravel (Rowley, 1975; Mackin and others, 1976), and locally, colluvium, landslide deposits, and bouldery debris flow deposits.

Stream alluvium: Pleistocene and Holocene alluvial deposits consist of sand and pebble gravel deposited in intermittent stream channels and flood plains.

GROUND-WATER CONDITIONS IN CEDAR VALLEY DRAINAGE BASIN

Introduction

Ground water in the Cedar Valley area occurs in two types of aquifers: fractured bedrock and unconsolidated deposits. Bjorklund and others (1978) report that the Upper Cretaceous bedrock units yield water to springs and a few wells, and Montgomery (1980) reports on the potential for water development in the Navajo Sandstone, but fractured bedrock aquifers are relatively unused in the Cedar Valley area. Ground water in the Cedar Valley area is obtained principally from unconsolidated deposits of the basin-fill aquifer (Thomas and Taylor, 1946; Sandberg, 1966; Bjorklund and others, 1978).

Basin-Fill Aquifer

Occurrence

Ground water in the Cedar Valley basin-fill aquifer occurs under confined, unconfined, and perched conditions in unconsolidated basin-fill deposits (figure 7) (Bjorklund and others, 1978). Based on water-well data, the thickness of Quaternary basin fill is estimated to be at least 1,000 feet (300 m) (Thomas and Taylor, 1946; Anderson and Mehnert, 1979), but geophysical data indicate that the basin fill may be as much as 3,900 feet (1,200 m) thick in the eastern part of the complexly faulted Cedar Valley graben (Cook and Hardman, 1967; Hurlow, in preparation). The unconsolidated basin fill consists primarily of Quaternary alluvial sediments,

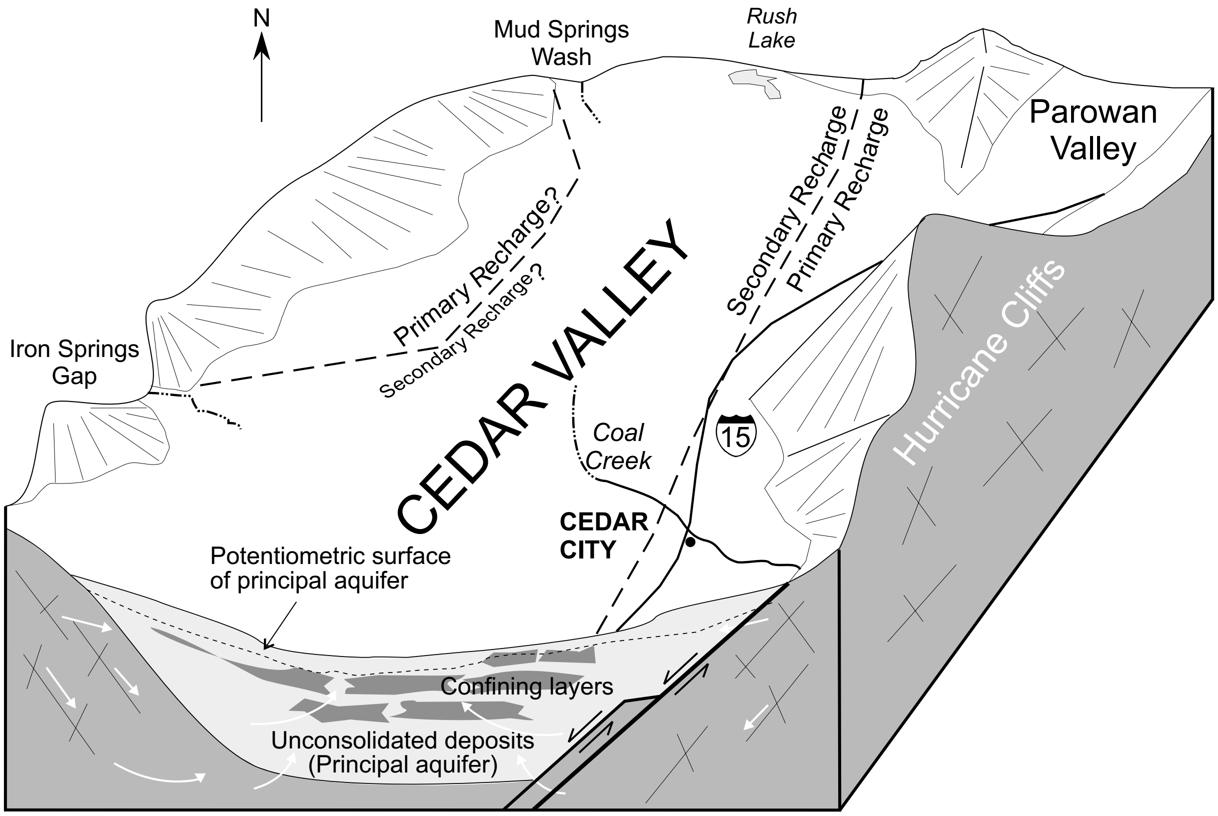

Figure 7. *Schematic block diagram showing ground-water conditions in Cedar Valley, Iron County, Utah.*

composed of discontinuous, lenticular, commonly elongated, poorly to well-sorted bodies of sand, clay, gravel, and boulders (Thomas and Taylor, 1946), interbedded with lava flows and containing some lacustrine and eolian deposits (Bjorklund and others, 1978). The basin-fill aquifer is generally under unconfined conditions along the higher elevation margins of Cedar Valley where it typically consists of coarse, granular, permeable sediments (Bjorklund and others, 1978) deposited primarily in alluvial fans (Thomas and Taylor, 1946).

The basin-fill aquifer is generally under leaky confined conditions in the central, lower elevation areas of the valley (figure 7) (Sandberg, 1966; Bjorklund and others, 1978) where water yielding coarser grained deposits are overlain by or interbedded with beds of low-permeability silt and clay (Bjorklund and others, 1978). The low-permeability sediments are extensive enough to locally form effective confining layers, but they are not continuous enough to form major separations in the basin fill where the ground-water system acts as a single, complex aquifer (Thomas and Taylor, 1946). The boundary between confined and unconfined conditions is indefinite and gradational, and shifts as the potentiometric surface of the basin-fill aquifer system rises and falls with changes in recharge and discharge (Bjorklund and others, 1978). Upward ground-water gradients in the central, lower elevation areas of Cedar Valley were once sufficient to supply flowing (artesian) wells that covered an approximate area of 50 square miles (130 km^2) in 1939 (Thomas and Taylor, 1946, plate 18), including the Bauers Knoll and Mid Valley Estates subdivision areas, but no flowing wells have existed in Cedar Valley since 1975 (Bjorklund and others, 1978). Primary ground-water recharge areas, where the basin fill is coarse and lacks thick fine-grained layers, occupy the margins of Cedar Valley. The central part of the valley is a secondary ground-water recharge area, containing thick fine-grained layers, with an overall downward ground-water flow gradient (figure 7). Discharge areas, where ground-water flow has an upward gradient, are present near Quichapa Lake, Rush Lake, and in an area just west of the town of Enoch (Bjorklund and others, 1978). The discharge areas near Quichapa and Rush Lakes are manifested as ephemeral surface water.

Aquifer Characteristics

The alluvial deposits yield water at rates ranging from 1 to 4,000 gallons per minute (4 15,100 L/min) (Bjorklund and others, 1978). The most productive aquifers consist of beds of coarse, clean, well-sorted gravel and sand that readily yield large quantities of water to wells (Bjorklund and others, 1978). Sandberg (1966), based on data from 10 wells in the Cedar Valley basin-fill aquifer, calculated a range for specific capacity of 10 to 50 gallons per minute per foot of drawdown (12-58 L/min per m of drawdown) with an average of 28 gallons per minute per foot of drawdown (32 L/min per m of drawdown). Bjorklund and others (1978) compiled data from six multiple-well aquifer tests completed in gravelly aquifer material in Cedar Valley and calculated a range for average hydraulic conductivity values of 13 to 251 feet per day (4-77 m/d), a transmissivity range of 2,540 to 52,000 square feet per day (230-4,830 m^2/d), and a storage coefficient range of 0.0005 to 0.2.

The Coal Creek alluvial fan, about 3 miles (5 km) north and northwest of Cedar City where the basin-fill aquifer is under leaky confined conditions, consists of coarse, well-sorted alluvium and has some of the highest transmissivities in Cedar Valley, estimated at about 20,000 square feet per day (2,000 m^2/d) (Bjorklund and others, 1978). Transmissivities in the Coal Creek alluvial fan decrease northward and westward to about 5,000 square feet per day (460 m^2/d) as the alluvial deposits become finer grained (Bjorklund and others, 1978). Near Enoch, Bjorklund and others (1978) estimated a transmissivity of 5,200 square feet per day (480 m^2/d) for an aquifer test on a well completed in the unconfined portion of the basin-fill aquifer.

Other areas with high transmissivities include the area just southwest of Quichapa Lake, where the basin fill is derived from Tertiary volcanic rocks in the mountains on the southwest side of Cedar Valley, and areas near and northeast of Rush Lake, where the basin fill contains permeable volcanic rock layers (Bjorklund and others, 1978). West of Quichapa Lake, Bjorklund and others (1978) estimated a transmissivity of about 42,000 square feet per day (3,900 m^2/d) for an aquifer test on a well completed in the leaky confined portion of the basin-fill aquifer. Transmissivities in the leaky confined aquifer in the Rush Lake area range from 5,000 to 20,000 square feet per day (500-2,000 m^2/d) (Bjorklund and others, 1978).

Transmissivities are somewhat lower in southern Cedar Valley. Based on two aquifer tests and estimates from specific capacity data, Bjorklund and others (1978) calculated transmissivities ranging from 2,000 to 10,000 square feet per day (200-900 m^2/d) in the Hamiltons Fort/Kanarraville Creek area.

The finer grained silt and clay layers store large quantities of water, but have low transmissivities and do not readily yield water to wells. Of the estimated 20 million acre-feet (25 km^3) of water stored in Cedar Valley's basin-fill aquifer system (Bjorklund and others, 1978), only 20 percent, or 4 million acre-feet (5,000 hm^3), is considered recoverable.

Potentiometric Surface

General: The potentiometric surface of ground water in the Cedar Valley basin-fill aquifer (figure 8) is irregular and depends on the well depth, season, and year when water-level measurements are made (Thomas and Taylor, 1946). In unconfined parts of the aquifer, the potentiometric surface corresponds to the water table; in the confined parts of the aquifer, the potentiometric surface represents the hydrostatic pressure, or head, a parameter controlling the elevation to which water will rise in wells). The potentiometric surface indicates horizontal ground-water flow direction, hydraulic gradient, and a predictable depth to water in wells in the unconfined portion of the aquifer.

Ground-water flow direction: Ground-water flow is generally from the higher elevation recharge areas to lower elevation discharge areas (figure 8). In southern Cedar Valley, ground water flows northward from the Kanarraville area, northeastward from the Harmony Mountains, southeastward from the Eightmile Hills, and west-northwestward from the North Hills toward Quichapa Lake (figure 8) (Bjorklund and others, 1978, plate 5). Ground water in the vicinity of the Coal Creek alluvial fan moves northward and northwestward from the apex of the fan and then either moves southward toward Quichapa Lake or westward toward Iron Springs Gap (figure 8) (Thomas and Taylor, 1946). Ground water in northern Cedar Valley generally moves northwestward toward Rush Lake and then continues toward Mud Spring Wash (figure 8) (Bjorklund and others, 1978). Hydraulic gradients are generally flat in the central, lower elevation areas of Cedar Valley, such as near Quichapa Lake. Hydraulic gradients are estimated to be about 25 feet per mile (5 m/km) at Iron Springs Gap and 50 feet per mile (9 m/km) at Mud Spring Wash (Sandberg, 1966).

Water levels in wells: Depth to ground water in wells ranges from near the ground surface in the central portion of the valley to about 250 feet (76 m) below the surface along the valley margins (Bjorklund and others, 1978). Most wells record static water levels less than 100 feet (30 m) below the land surface. Depths to ground water in wells in the Coal Creek alluvial-fan area range from about 200 feet (60 m) near Cedar City to about 10 feet (3 m) in the distal portions of the fan (Bjorklund and others, 1978). Depths to ground water range from about 150 feet (46 m) along the mountain front to about 10 feet (3 m) in the lower portions of the valley in the Hamiltons Fort/Kanarraville area, from about 10 feet (3 m) near Quichapa Lake to about 100 feet (30 m) along the mountain front to the southwest, and from about 10 feet (3 m) near Rush Lake to about 50 feet (15 m) a few miles northeast of Rush Lake (Bjorklund and others, 1978).

Changes in water levels: The level at which water stands in wells in the Cedar Valley basin-fill aquifer varies in response to changes in the hydrostatic pressure of the ground water, which varies due to changes in the amount of water: (1) withdrawn from pumping wells, (2) discharging by evapotranspiration, and (3) infiltrating and recharging the system from rainfall, irrigated lands, stream channels, and irrigation ditches (Thomas and Taylor, 1946). The changes in hydrostatic pressure can be either seasonal or long term.

The withdrawal of large amounts of ground water during the irrigation season causes seasonal changes in water levels (Sandberg, 1966), as does seasonal variation in precipitation and streamflow (Thomas and Taylor, 1946). There is a general pattern of declining water levels during the irrigation season, typically from May through September, and rising water levels from October through May (Bjorklund and others, 1978). Seasonal changes in ground-water levels exceeding 30 feet (9 m) were observed in 1974 in the center of the valley northwest of Cedar City, but water levels declined less than 5 feet in most areas along the western side of the valley during the same year (Bjorklund and others, 1978, figure 6).

Long-term changes in water level depend on annual average precipitation and evapotranspiration, and on average annual well pumpage. Between 1940 and 1974, the amount of ground-water discharge from wells, springs, and evapotranspiration exceeded recharge to the ground-water system which resulted in an overall decline in ground-water levels in the basin-fill aquifer. Due to concerns caused by declining water levels, the Utah State Engineer closed Cedar Valley's entire subbasin to new appropriations of water rights in 1966; portions of Cedar Valley had already been closed to new appropriations since the 1940s (Utah Division of Water Resources, 1995). Average annual ground-water levels declined as much as 30 feet (9 m) in some areas of Cedar Valley between 1940 and 1974, which was attributed primarily

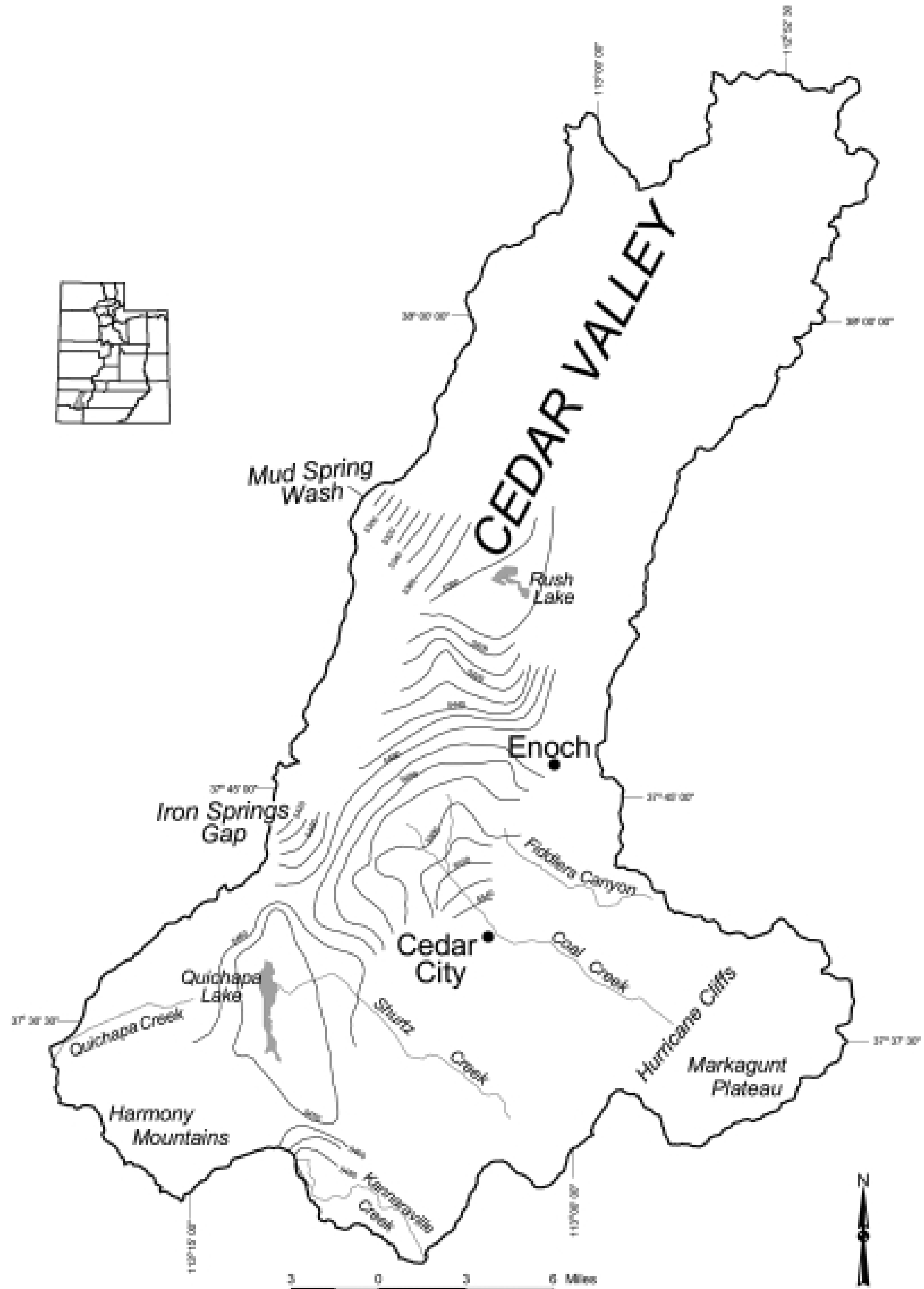

Figure 8. *Potentiometric surface map for basin-fill aquifer, Cedar Valley, Iron County, Utah (from Bjorklund and others, 1978). Ten-foot contour intervals.*

to withdrawal by wells (Bjorklund and others, 1978, figure 11). Between 1963 and 1993, water-level declines greater than 10 feet (3 m) were limited to the area west of Quichapa Lake (Barnett and Mayo, 1966), indicating long-term recharge and discharge are relatively in balance (Utah Division of Water Resources, 1995).

Recharge

Most recharge to the basin-fill aquifer comes directly or indirectly from precipitation within the Cedar Valley drainage basin (Sandberg, 1966). However, of the 452,000 acre-feet (557 hm^3) of average annual precipitation that falls within the drainage basin, recharge to the basin-fill aquifer is estimated to be only about 40,000 acre-feet per year (49 hm^3/yr) as most of the precipitation is consumed by evapotranspiration before entering the aquifer system (Bjorklund and others, 1978). Negligible recharge to the basin-fill aquifer likely comes from direct precipitation on the valley floor, and is related to soil-moisture deficiencies in the unsaturated zone. Uptake by plants/phreatophytes typically utilizes the available amount of moisture from precipitation at the surface providing only a minor, if any, amount to percolate below the root zone to the zone of saturation (Thomas and Taylor, 1946).

Streams are the main source of recharge to the basin-fill aquifer, and most recharge occurs in the upper portions of the highly permeable alluvial-fan deposits along the margins of the valley (Bjorklund and others, 1978). Although many smaller drainages entering Cedar Valley likely contribute some intermittent recharge, especially after snowmelt or during major precipitation events, Coal Creek supplies the greatest amount of recharge in Cedar Valley (Thomas and Taylor, 1946). Bjorklund and others (1978) identified ground-water mounds with water-table slopes radiating away from the fan axes under several alluvial fans. Urbanization and the accompanying introduction of impermeable materials (for example, pavement) may result in less recharge along alluvial fans, eventually altering flows in drainages and re-channeling water courses toward the valley where less favorable recharge areas exist (Utah Division of Water Resources, 1995).

Excess irrigation water, either diverted from streams or pumped from wells, is also an important source of recharge to the basin-fill aquifer, especially along the valley margins where unconsolidated deposits are most permeable (Thomas and Taylor, 1946). Most of the average annual flow of Coal Creek, about 24,000 acre-feet per year (30 hm^3/yr), is diverted for irrigation (Bjorklund and others, 1978).

Subsurface inflow from Parowan Basin in the north and the surrounding adjacent mountain blocks may contribute a relatively small amount of recharge to the basin-fill aquifer in Cedar Valley. Subsurface inflow from consolidated rock is likely greatest at the contacts between the basin fill and the Tertiary Claron Formation, Tertiary and Quaternary volcanic rocks, and the Jurassic Navajo Sandstone (Bjorklund and others, 1978).

Discharge

Ground water is discharged from the basin-fill aquifer by springs and seeps, evapotranspiration, wells, and subsurface outflow from the area (Sandberg, 1966). The average annual discharge in Cedar Valley is about 44,000 acre-ft (54 hm^3) (Bjorklund and others, 1978).

Springs and seeps in Cedar Valley issue from three main areas: (1) the Enoch/Rush Lake area near the contact between consolidated rock and unconsolidated deposits, (2) the area west of Rush Lake, and (3) the area near Quichapa Lake (Sandberg, 1966). However, springs and seeps account for only minor discharge in the basin-fill aquifer (Bjorklund and others, 1978). Thomas and Taylor (1946) estimated a total average annual natural discharge within Cedar Valley of about 4,700 acre-feet per year (6 hm^3/yr), but many of the springs and seeps that emanated in the Rush Lake and Enoch area in 1940 were dry by 1974 (Bjorklund and others, 1978).

Evapotranspiration represents about 3,600 acre-feet per year (4.4 hm^3/yr) of annual average discharge: about 2,000 acre-feet per year (2.5 hm^3/yr) by evapotranspiration by phreatophytes in Cedar Valley and by evaporation from the playas at Rush and Quichapa Lakes, and about 1,600 acre-feet per year (2 hm^3/yr) from areas where the potentiometric surface of the basin-fill aquifer is within 10 feet (3 m) of the ground surface (Bjorklund and others, 1978). Although estimated during the 1970s, the numbers likely reflect the current evapotranspiration rates (Utah Division of Water Resources, 1995).

Subsurface outflow from Cedar Valley is possible at three locations: Iron Springs Gap, Mud Spring Wash, and Kanarraville Creek valley (Thomas and Taylor, 1946). Bjorklund and others (1978) estimated an average annual subsurface discharge from Cedar Valley of about 500 acre-feet per year (0.6 hm^3/yr) at Iron Springs Gap and 20 acre-feet per year (0.025 hm^3/yr) at Mud Spring Wash; they estimated subsurface discharge to Kanarraville Creek valley as negligible.

Withdrawal from wells currently represents the greatest amount of ground-water discharge from the basin-fill aquifer (Utah Division of Water Resources, 1997). In 1975, almost 43,000 acre-feet (53 hm^3) of ground water was pumped for irrigation, municipal supply, domestic, and stock use (Bjorklund and others, 1978). By 1993, the annual pumpage had decreased to about 35,000 acre-feet (43 hm^3) (Utah Division of Water Resources, 1997). Annual pumpage varies considerably depending on cumulative departure from average annual precipitation and is considerably higher during drought years (Thomas and Taylor, 1946).

Water Quality

Ground water in Cedar Valley is generally of good quality and, although classified as hard, is suitable for most uses (Utah Division of Water Resources, 1995). Ground water in the basin fill aquifer is generally classified as calcium- or magnesium-sulfate type. Sodium-chloride-type ground water is present near Rush Lake and calcium-bicarbonate-type ground water is present southwest of Quichapa Lake (Bjorklund and others, 1978). Thomas and Taylor (1946) reported total-dissolved-solids (TDS) concentrations ranging from about 150 mg/L (for the ranges of TDS and nitrate concentrations used in this report, mg/L equals parts per million), just west of Quichapa Lake, to more than 1,700 mg/L for certain wells on the Coal Creek alluvial fan. Bjorklund and others (1978, table 5) reported TDS concentrations in ground water ranging from 166 to 2,752 mg/L. Sandberg (1966) reported TDS concentrations in ground water ranging from 281 to 3,750 mg/L.

The type of water and quantity of dissolved solids is largely influenced by local geology. Ground water with high TDS concentrations and high calcium and sulfate concentrations exists in the Coal Creek and Fiddlers Canyon alluvial-fan areas because Mesozoic-age rocks in the drainage basin contain abundant gypsum (Thomas and Taylor, 1946). Ground water with high TDS concentrations and high sodium and chloride concentrations exists near the playa areas of Rush and Quichapa Lakes (Bjorklund and others, 1978). Ground water in the area recharged by Quichapa Creek has low TDS concentrations and is the softest water in the basin-fill aquifer, because its drainage basin is underlain almost exclusively by Tertiary volcanic rocks which contain few soluble minerals.

In addition to calcium, sulfate, and chloride, another chemical constituent, nitrate, typically associated with human activities, has been identified in Cedar Valley. Nitrate concentrations in ground water have been analyzed and reported in two different ways in the literature for Cedar Valley: nitrate as nitrogen and nitrate as nitrate. The values for nitrate as nitrate are much higher than the corresponding values for nitrate as nitrogen. The Utah ground-water-quality (health) standard for nitrate is 10 mg/L for nitrate as nitrogen and 45 mg/L for nitrate as nitrate.

Thomas and Taylor (1946, p. 107) reported nitrate-as-nitrate concentrations ranging from 0 to 260 mg/L for wells in Cedar Valley (table 1); they noted that the highest nitrate concentration in ground water was found in the Fiddlers Canyon alluvial-fan area, and that this high-nitrate ground water also contained high chloride and sulfate concentrations. Some of the wells in the Coal Creek alluvial-fan area were also high in nitrate and sulfate, but not high in chloride concentrations (Thomas and Taylor, 1946, p. 107). Sandberg (1963, 1966) reported nitrate-as-nitrate concentrations in Cedar Valley ranging from 1 to 109 mg/L (table 2). Bjorklund and others (1977, 1978) reported nitrate-as-nitrogen concentrations in Cedar Valley ranging from 0 to 14 mg/L (table 3).

Thomas and Taylor (1946) noted that nitrate concentrations over a few mg/L in shallow ground water is considered an indication of water-quality degradation typically associated with human-related activities. However, they noted (Thomas and Taylor, 1946, p. 110) that depths for most of the wells having high nitrate concentration in Cedar Valley exceed 100 feet (30 m), suggesting a geologic source of nitrate possibly associated with soluble salts in the valley fill rather than an anthropogenic origin.

Figure 9 shows the distribution of nitrate concentrations in ground water in Cedar Valley based on the data presented in tables 1, 2, and 3. Nitrate-as-nitrate values have been converted to nitrate-as-nitrogen values. Figure 10 shows the percentage of wells having nitrate concentrations less than 5 mg/L, between 5 and 10 mg/L, and greater than 10 mg/L for wells within and outside the Enoch area, respectively, for this data set. Note that most of the high-nitrate wells are in the Enoch area; the data indicate an anomalously higher concentration of nitrate in ground water in the Enoch area compared to ground water in the rest of Cedar Valley. Nineteen percent of the wells in the Enoch area exceed the ground-water-quality standard for nitrate of 10 mg/L and the average nitrate concentration is 6.95 mg/L, whereas 7.8 percent of the wells outside of the Enoch area exceed the standard and the average nitrate concentration is 2.39 mg/L (figure 9).

Table 1.
Nitrate concentration in ground water for water wells in Cedar Valley, Iron County, Utah (data from Thomas and Taylor, 1946).

Well location	Well depth (feet)	Nitrate (as NO_3) ppm
(C-34-11)36adc	200	2.8
(C-35-10)7cad	101	0.9
(C-35-11)1acc	150	4.2
(C-35-11)1ccd	156	2.5
(C-35-11)12ddd	250	2.7
(C-35-11)14ddd	158	125
(C-35-11)23bdc	100	260
(C-35-11)26bbb	140	144
(C-35-11)21dcc	180	10
(C-35-11)22dcc	61	17
(C-35-11)27aca	108	56
(C-35-11)27acc	113	13
(C-35-11)27adc	148	44
(C-35-11)32aca	175	11
(C-35-11)33aac	138	16
(C-35-11)19bda	175	0
(C-35-11)29abd	100	4.7
(C-36-11)5baa	132	10
(C-36-11)8aab	103	58
(C-36-11)8cab	200	18
(C-36-11)8cbb	60	21
(C-36-11)10bcc	195	8.5
(C-36-11)18ada	230	29
(C-36-11)7baa	167	12
(C-36-12)1aaa	366	0.5
(C-36-12)10ada	389	1
(C-36-12)9aaa	257	0.8
(C-36-12)12dac	200	0.8
(C-34-11)36cbc	60	0
(C-35-11)2ddd	40	0
(C-35-11)8ddd	178	0.9
(C-35-11)9add	151	1.3
(C-35-11)10dbd	90	22
(C-35-11)15dba	84	49
(C-35-11)16dba	104	13
(C-35-11)17dad	270	8
(C-33-11)29ccb	72	1
(C-33-11)30bca	60	0
(C-34-11)13bab	200+	1.2

LAND-USE PRACTICES IN THE ENOCH AREA

We define the Enoch study area as all of Township 35 South and Range 11 West (included in both Enoch and Cedar City 7.5' quadrangles), and the lower reaches of the Fiddlers Canyon drainage basin and alluvial fan (plate 1); this area includes the Enoch and Midvalley ground-water districts as defined by Thomas and Taylor (1946). The Enoch area has experienced two phases of land-use practices. Beginning with its settlement in 1864 (Utah League of Cities and Towns, 2000), Enoch was primarily a farming and grazing community with low density residential development; this early agricultural phase continued until the 1970s when higher density residential development began. During the earlier agricultural phase, alfalfa was the principal crop, with corn and grains used in rotation; this type of farming was also predominant throughout the rest of Cedar Valley (Joe Melling, verbal communication, February 20, 2001). In general, fertilizer was not applied in these farming operations, and when used, was typically cow manure. Dairy operations were more common throughout Cedar Valley in the mid 1900s.

Table 2.
Nitrate concentration in ground water for water wells in Cedar Valley, Iron County, Utah (data from Sandberg, 1966).

Well location	Nitrate (as N) ppm
(C-33-10)29adc	109
(C-33-12)11aaa	1.3
(C-34-11)36cdd	1.8
(C-35-11)13dda	20
(C-35-11)33aac	1.1
(C-35-12)34dcd	2.9
(C-36-11)18ada	27
(C-36-11)18bdc	6
(C-36-12)12dba	7.8
(C-36-12)20acc	2.4
(C-36-12)33bdc	0.8
(C-37-12)11aab	3
(C-37-12)23acb	1
(C-37-12)23bbd	66
(C-37-12)34abb	15

Table 3.
Nitrate concentration in ground water for water wells in Cedar Valley, Iron County, Utah (data from Bjorklund and others, 1977).

Well location	Well depth (feet)	Nitrate (as N) ppm
(C-33-11)30bca	80	0.3
(C-34-10)31caa	365	2.6
(C-34-11)1daa	120	1.2
(C-34-11)9ccd	130	0.22
(C-34-11)23bdd	302	1.1
(C-34-12)36abb	-	0.35
(C-35-10)18cca	285	0.99
(C-35-11)26acd	700	14
(C-35-11)33aac	236	4
(C-35-12)20abc	-	0.5
(C-35-12)27bcd	255	0.26
(C-36-10)18bcd	147	0.69
(C-36-11)11bac	670	8.4
(C-36-12)32ccb	697	0
(C-37-12)11aaa	365	0.9

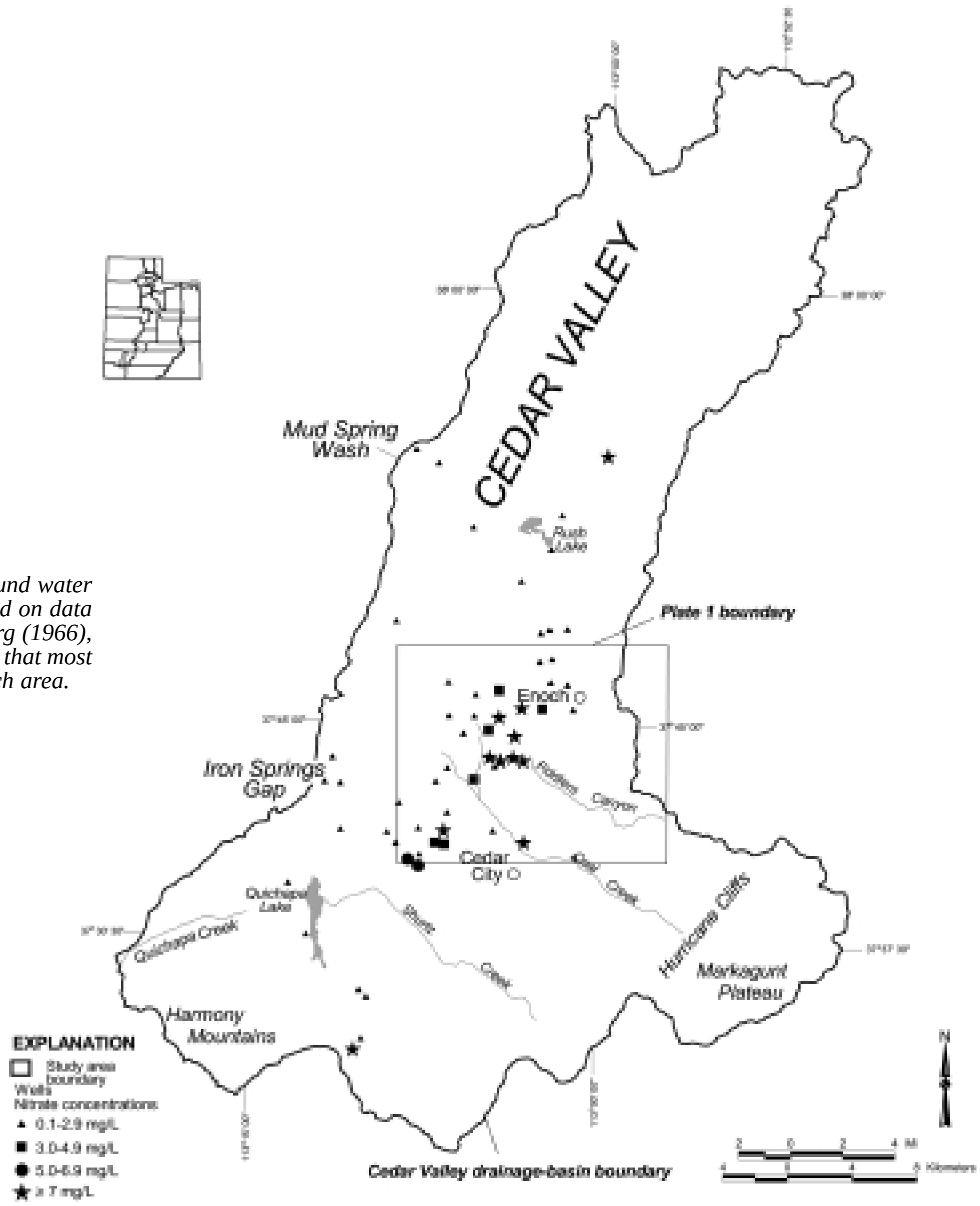

Figure 9. *Nitrate concentrations in ground water in Cedar Valley, Iron County, Utah, based on data from Thomas and Tayler (1946), Sandberg (1966), and Bjorklund and others (1977). Notice that most of the high-nitrate values are in the Enoch area.*

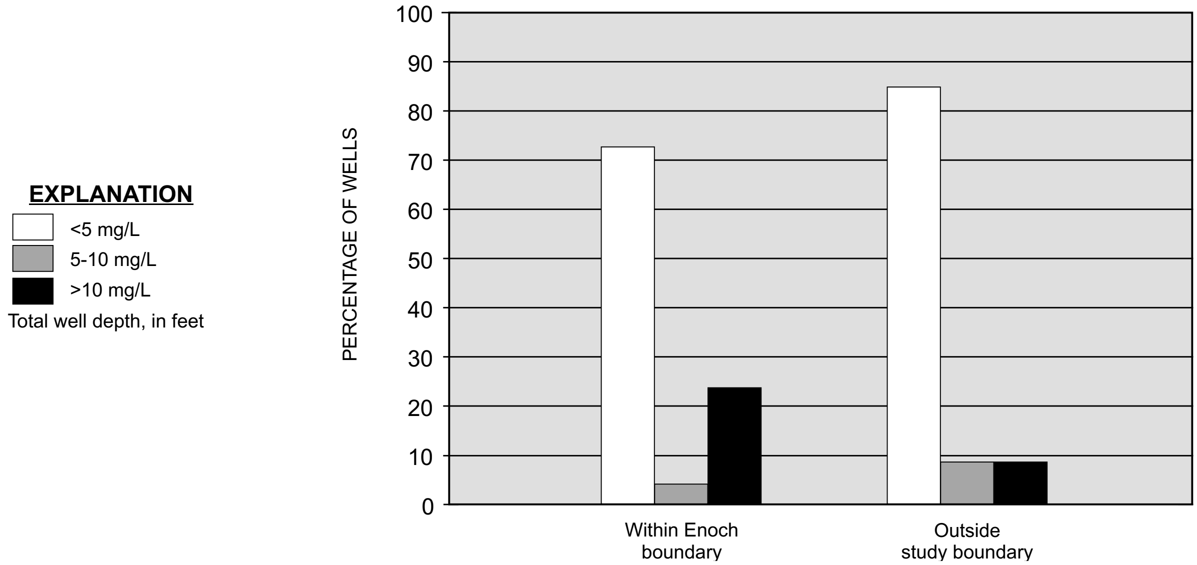

Figure 10. *Percentage of wells having nitrate concentrations <5mg/L, 5-10mg/L, and >10mg/L within and outside the Enoch study-area boundary in Cedar Valley, Iron County, Utah, based on data collected by Thomas and Taylor (1946), Sandberg (1966), and Bjorklund and others (1978). The number of wells sampled within the Enoch boundary is 25, outside the area is 39.*

The largest dairy operation was located just west of the Cedar City airport and housed 150 to 200 cows (Joe Melling, verbal communication, February 20, 2001). In the Enoch area, near the intersection of Mid Valley and Minersville roads, a dairy housed about 30 cows. Just south and southwest of old Enoch town, residential development has replaced a large irrigation pond and alfalfa fields (Gaylen Matheson, verbal communication, February 21, 2001).

Residential development became the predominant land use in the Enoch area during the 1970s, after the city was incorporated in 1966 (Utah League of Cities and Towns, 2000); wastewater disposal was primarily accomplished via septic-tank systems until 1994 when the construction of the sanitary sewer system began. Construction of this sewer was completed in 1996. About 700 homes originally were connected to the common sewer. Today, approximately 1,100 homes are connected (Gaylen Matheson, verbal communication, February 21, 2001), but some areas in the northern part of the Enoch area and west of the city boundary use septic-tank systems as their primary method of wastewater disposal. This pattern of land use took place much earlier in Cedar City, which became incorporated in 1868 (Utah League of Cities and Towns, 2000) and used cesspools and septic-tank systems for wastewater disposal until the late 1920s when sewer lines were constructed. From the 1930s to the mid 1970s, these sewer lines conducted wastewater to an area on the southeast side of Cedar City where the effluent and solid waste was applied to 100 to 200 acres (0.4-0.8 km^2) (Joe Melling, verbal communication, February 21, 2001).

During the earlier agricultural phase in the Enoch area, similar land-use practices occurred in other areas of Cedar Valley. Residential development and wastewater disposal in the Enoch area parallel much earlier, higher density residential development and wastewater disposal in Cedar City. Cedar City, though experiencing similar land-use development as Enoch, has maintained lower nitrate concentrations in water wells. We believe land-use practice alone cannot explain the anomalously high nitrate concentrations found in ground water in the Enoch area.

GEOLOGY OF THE ENOCH STUDY AREA

Introduction

Historically high nitrate concentrations in ground water in the Enoch area of Cedar Valley are well documented, as noted above, and human activities unique to the Enoch area do not seem to explain their occurrence. Therefore, the following discussion emphasizes the geology and hydrogeology of areas that might be contributing to elevated nitrate levels, and evaluates short- and long-term trends in nitrate concentration in the ground water in Enoch area.

Structure and Geomorphology

The Markagunt Plateau comprises the surface-drainage basin and principal recharge area for ground water in the Enoch area. Based on Thomas and Taylor's (1946) interpretation, two projected northeast-trending faults (the Enoch and West Enoch faults, plate 1) exist in the Enoch area to the west of the east-side-up Hurricane fault zone at the base of the Hurricane Cliffs. These faults bound the "Enoch graben," and, at the surface, displace Quaternary sediments and Tertiary volcanic rocks. The Enoch fault is largely concealed by recent alluvium, but can be traced through some bedrock outcrops (Thomas and Taylor, 1946). The West Enoch fault is mostly concealed, and interpreted based on the presence of springs to the north, differences in ground-water quality on either side of the fault in the Midvalley area (Thomas and Taylor, 1946), and extrapolation to faults exposed to the south, just northwest of Cedar City, in the Cedar City quadrangle. The Enoch and West Enoch faults form the boundaries of Thomas and Taylor's (1946) Enoch ground water district.

The southeastern part of the Enoch study area includes the broad, bouldery Fiddlers Canyon alluvial fan (figure 11) at the mouth of Fiddlers Canyon. Ephemeral Fiddlers Creek incises west-dipping Mesozoic sedimentary rocks (figure 12, plate 1) which are mantled locally by Quaternary alluvium.

Figure 11. *View to the east of Fiddlers Canyon alluvial fan and recently drilled U.S. Geological Survey monitoring water well.*

Figure 12. *Upstream view of creek in Fiddlers Canyon and the west-dipping Cretaceous Straight Cliffs Formation. Creek is about 3 feet (1 m) wide.*

In the eastern and northeastern part of the Enoch area, Tertiary volcanic rocks mantled locally by Quaternary alluvium crop out in the southern terminus of the low-lying Red Hills.

Distribution of Stratigraphic Units

Introduction

Rock units exposed in the Enoch area range in age from Triassic to Quaternary (Averitt and Threet, 1973; Rowley and Threet, 1976). Mesozoic rocks in the study area are approximately 4,000 feet (1,200 m) thick; Tertiary volcanic units in the northern part of the area are up to hundreds of feet thick, but vary locally in thickness. Based on drillers' logs of water wells and information from an abandoned oil well, Quaternary-Tertiary alluvial fill is up to 800 feet (240 m) thick and likely exceeds 1,000 feet (300 m) at some locations in the Enoch area. The characteristics of the stratigraphic units are described in detail above and are shown on plate 1.

Mesozoic Rocks

Mesozoic rocks are predominantly located in the Fiddlers Canyon area and south to Coal Creek in the southeastern part of the Enoch study area (plate 1). The steeply northwest-dipping rocks situated along the eastern margin of Cedar Valley in the Enoch study area consist mostly of sandstone with minor siltstone and limestone; they dip steeply east to southeast near Cedar City.

The Triassic Moenkopi and Chinle Formations crop out at the base of the Hurricane Cliffs near Cedar City and in lower Cedar Canyon in the south-central part of the Enoch study area (plate 1).

The Jurassic Moenave, Kayenta, and Navajo Formations crop out higher up on the Hurricane Cliffs and Cedar Canyon. Relatively minor exposures of the Crystal Creek, Paria River, and Winsor Members of the Middle Jurassic Carmel Formation are present in upper Fiddlers Canyon (Averitt and Threet, 1973); these members are not differentiated on Plate 1. The Carmel Formation crops out extensively in upper Cedar Canyon (plate 1).

The oldest Cretaceous rocks are the Dakota Formation, which crops out along much of the south side and upper reaches of Fiddlers Canyon (plate 1) (Averitt and Threet, 1973). The Late Cretaceous Straight Cliffs Formation overlies the Dakota Formation and is the dominant stratigraphic unit exposed in the Fiddlers Canyon drainage basin (Averitt and Threet, 1973; Rowley and Threet, 1976); some of the tributaries to Coal Creek are also incised into this unit (plate 1). The creek in Fiddlers Canyon and the much larger, perennial Coal Creek are the only drainages in the Cedar Valley drainage basin to cut through Straight Cliffs Formation strata. Minor exposures of the Late Cretaceous Wahweap Sandstone are present at the mouth of Fiddlers Canyon (Averitt and Threet, 1973).

Tertiary Rocks

Outcrops of the Paleocene-Oligocene Claron Formation in the Enoch area are located along the southwestern border of the Red Hills and on the Fiddlers Canyon alluvial fan just east of Interstate 15 (Averitt and Threet, 1973; Rowley and Threet, 1976).

Tertiary volcanic rocks are typically faulted in the Enoch area. Tertiary volcanic rocks crop out at the southern terminus of the Red Hills and in a small outcrop along and just east of Interstate 15 in sections 24 and 25, T. 35 S., R. 11 W., Salt Lake Base Line and Meridian (plate 1). The Teritary rocks are undivided in the eastern part of the Enoch study area.

The moderately resistant Oligocene Needles Range Formation crops out locally along the base of the Red Hills in the Enoch area, and the Bald Hills Tuff Member of the Miocene-Oligocene Isom Formation is exposed above the Hurricane Cliffs just south of the southwest end of Parowan Valley, and in the southern Red Hills. These rock units are lumped as one unit (Tin) on plate 1.

A number of formations of the Miocene Quichapa Group are exposed in the Enoch study area (plate 1). The Leach Canyon Formation in the Enoch area consists of the lower Narrows Tuff Member and upper Table Butte Tuff Member (Mackin and Rowley, 1976; Hintze, 1988), and is exposed along Interstate 15 in sections 24 and 25, T. 35 S., R. 11 W., Salt Lake Base Line and Meridian, and in the Red Hills. The Bauers Tuff Member of the Condor Canyon Formation is exposed along the base of the western margin of the Red Hills. The Harmony Hills Tuff has limited exposure at the southern end of the Red Hills in the Enoch area.

Quaternary-Tertiary

Miocene, Pliocene, and Pleistocene poorly consolidated sediments (QTs on plate 1) consist mostly of sandy fine-pebble to boulder conglomerate or, less commonly, coarse-grained sandstone or colluvium (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976). These sediments are found in the Elliker basin area in the northeast part of the Enoch study area (plate 1). Miocene, Pliocene, and Pleistocene alluvium (QTa on plate 1) consists of interbedded, poorly sorted, brown to tan gravel and tan to red silt (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976). These sediments mantle hilly areas around the valley margins in the eastern, nortwestern, and southern parts of the Enoch study area (plate 1), are locally interbedded with Quaternary-Tertiary basalt lava flows (Rowley, 1975, 1976; Mackin and others, 1976; Rowley and Threet, 1976), and are dissected by modern streams.

Minor exposures of Pliocene and Pleistocene basalt lava flows (not shown on plate 1) are present in the southern Red Hills, just east of the town of Enoch (Rowley, 1975, 1976; Rowley and Threet, 1976).

Quaternary

Quaternary basin-fill alluvium (Qa on plate 1) forms the land surface in the northwestern half of the study area and consists of unconsolidated clay, silt, and sand, predominantly alluvial in origin, but also contains some Pleistocene lacustrine deposits (Rowley and Threet, 1976). Quaternary alluvial-fan deposits (Qaf on plate 1) form the land surface in much of the southeastern part of the study area and consist predominantly of unconsolidated silt, sand, and minor pebbly gravel (Rowley, 1975; Mackin and others, 1976), and, locally, colluvium, landslide deposits, and bouldery debris-flow deposits. The Fiddlers Canyon alluvial fan contains a large proportion of debris-flow deposits. Quaternary basalt (Qb on plate 1) is found in the Enoch area east of the Hurricane fault zone. Large landslide deposits (Qm on plate 1) are found on the south side of the southwest end of Parowan Valley, and along the north side of Fiddlers Canyon (plate 1).

GROUND-WATER CONDITIONS IN THE ENOCH AREA

Introduction

Thomas and Taylor (1946) defined seven distinct ground-water reservoirs in Cedar Valley. The Enoch groundwater district is partitioned from the Midvalley and Coal Creek areas by the West Enoch fault (Thomas and Taylor, 1946). Numerous springs associated with the Enoch fault (plate 1) used to provide some water to the Enoch area (Thomas and Taylor, 1946); those springs no longer flow and most water supply comes from wells completed in unconsolidated basin-fill deposits.

Basin-Fill Aquifer

Occurrence

Ground water in the Enoch area occurs under confined, unconfined, and perched conditions in unconsolidated basin-fill deposits (Bjorklund and others, 1978). The deepest water well in the area, based on available driller's logs, penetrates approximately 800 feet (240 m) of alluvial material. The estimated thickness of Quaternary-Tertiary basin fill is 1,000 feet (300 m) (Thomas and Taylor, 1946). The unconsolidated basin fill consists primarily of Quaternary Tertiary alluvial sediment, which forms discontinuous, lenticular, commonly elongated, poorly to well-sorted bodies of sand, clay, gravel, and boulders (Thomas and Taylor, 1946). The basin-fill aquifer is generally under unconfined conditions along the higher elevation valley margins, especially near Fiddlers Canyon, where it consists of coarse, granular, permeable sediments (Bjorklund and others, 1978) deposited primarily in alluvial fans (Thomas and Taylor, 1946).

Geologic logs describing water-well cuttings for four different locations in the Enoch area corroborate the variable nature of alluvial fill and ground-water conditions. We describe well cuttings from proximal alluvial-fan to basin-center deposits in detail at 10-foot (3-m) intervals in appendix B. The wells are in sections 1, 9, 25, and 35, T. 35 S., R. 11 W., Salt Lake Base Line and Meridian (plate 1). The northernmost well, located in section 1, is 430 feet (130 m) deep and cuttings consist of light brownish-orange clay, silt, sand, and minor gravel (typically less than 1 percent per interval) (figure 13); the recorded water level in the well is 55 feet (17 m). The westernmost 460-foot-deep (140 m) well is located in section 9 in the distal reaches of the fan, and cuttings consist of alternating intervals of mixed light pinkish-brown, fine-grained sand, silt, and clay and 5- to 15-foot (1.5-4.6-m) gravel layers (figure 14); the recorded water level in the well is 20 feet (6 m). The two southeasternmost wells, located in sections 25 and 35 in the proximal portion of the alluvial fan, both had cuttings dominated by pink, tan, and gray gravel composed of volcanic, sandstone, limestone, and chert clasts with minor sand (figures 15 and 16); the wells are 320 and 300 feet (98 and 91 m) deep, respectively. The cuttings from wells in sections 25 and 35 represent the unconfined basin-fill aquifer, while cuttings from the wells in sections 1 and 9 represent the confined basin-fill portions of the aquifer. Sediment samples from selected intervals from the wells in sections 1 and 9 were also examined for the presence of nitrogen, which we discuss in a subsequent section.

The basin-fill aquifer is generally under leaky confined conditions in the central, lower elevation parts of the Enoch area (Sandberg, 1966; Bjorklund and others, 1978) and in distal portions of the alluvial fan, where water-yielding coarser grained deposits are capped by or contain intervening beds of low-permeability silt and clay (Bjorklund and others, 1978).

Potentiometric Surface

General: The potentiometric surface of ground water in the Enoch area basin-fill aquifer is variable. The water-table elevation in unconfined parts of the aquifer, and measured hydrostatic pressures in the confined parts of the aquifer, are irregular and depend on the well depth, the season, and the year during which water-level measurements were made (Thomas and Taylor, 1946).

Ground-water flow direction: Ground-water flow is generally from the higher elevation recharge areas to lower elevation discharge areas. Ground-water flow direction in the Enoch area is to the west, from the southwest end of Parowan Valley and from the unconsolidated alluvial-fan margin deposits to the east. Ground water continues west through the Midvalley ground-water district, and eventually northward toward Rush Lake and ultimately to Mud Spring Wash (Bjorklund and others, 1978).

Water levels in wells: Depth to ground water in wells is variable. Water levels, reported from various years and seasons on drillers' logs of water wells, range from 14 to 200 feet (4-61 m), but most wells have static water levels less than 100 feet (30 m) below the land surface. Shallower water levels are generally associated with the confined portion of the aquifer, typically in the distal reaches of the fan; water levels greater than 50 feet (15 m) and up to 200 feet (61 m) are typical along the eastern margin of the valley and in the proximal reaches of the alluvial fan. Northwest of Enoch, shallow ground water, typically less than 10 feet (3 m) below the ground surface, covers an area up to 1,600 acres (6.5 km^2) (Thomas and Taylor, 1946).

Water Quality in the Enoch Area

General

Ground water in the Enoch area is generally of good quality and is classified as pristine and drinking water quality according to the Utah Water Quality Board's classification system. Ground water in the basin-fill aquifer is generally classified as calcium- or magnesium-sulfate type, although sodium-chloride-type ground water is present near Rush Lake (Bjorklund and others, 1978). Total-dissolved-solids concentrations were obtained during 1979-81 for 34 wells in the Enoch area (Joe Melling, written communication, 1997). Total-dissolved-solids concentrations range from 233 to 2,524 mg/L, with an average of 812 mg/L.

As discussed above, nitrate concentrations in ground water have been analyzed and reported in various studies for decades in the Cedar Valley drainage basin (Thomas and Taylor, 1946; Sandberg, 1966; Bjorkland and others, 1978). As part of this study, we evaluated additional unpublished nitrate data from wells sampled by other agencies from 1979 to 1981 and from a well drilled and sampled by the U.S. Geological Survey in 1999, and conducted our own nitrate sampling in 1999; these data are from wells within the Enoch study area (plate 1).

Nitrate Data From 1979 To 1981

A total of 101 water wells were sampled for nitrate during 1979-81 (appendix C) in the Enoch area (Joe Melling, Cedar City Manager, written communication, 1997). Most of the wells are located throughout Township 35 South and Range 11 West. Joe Melling provided us with various reports from the 1979-81 sampling, including driller's logs for more than half of the wells sampled (59 of 100). Of those wells sampled in 1979-81, 33 wells were resampled by different agencies, including Southern Utah University (SUU), the state of Utah, and Ford Chemical. All of the laboratories report nitrate as nitrogen (in mg/L), the standard currently utilized by the U.S. Environmental Protection Agency. About 30 of the wells were tested seasonally, some up to 19 times per year.

In general, the nitrate values from the wells sampled in 1979-81 showed little seasonal fluctuation, with the excep-

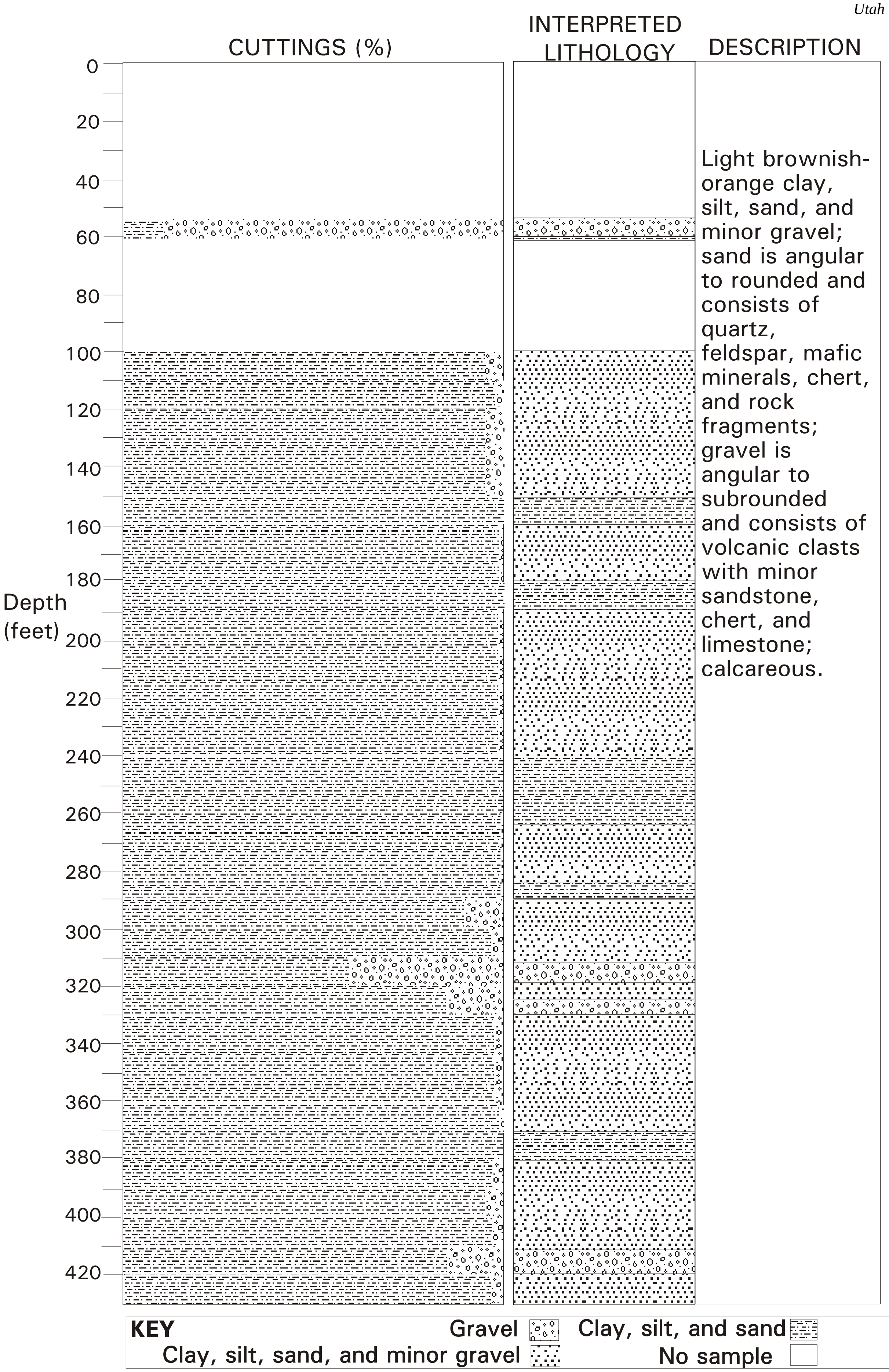

Figure 13. *Geologic log of water-well cuttings for well (C-35-11) 1bbb.*

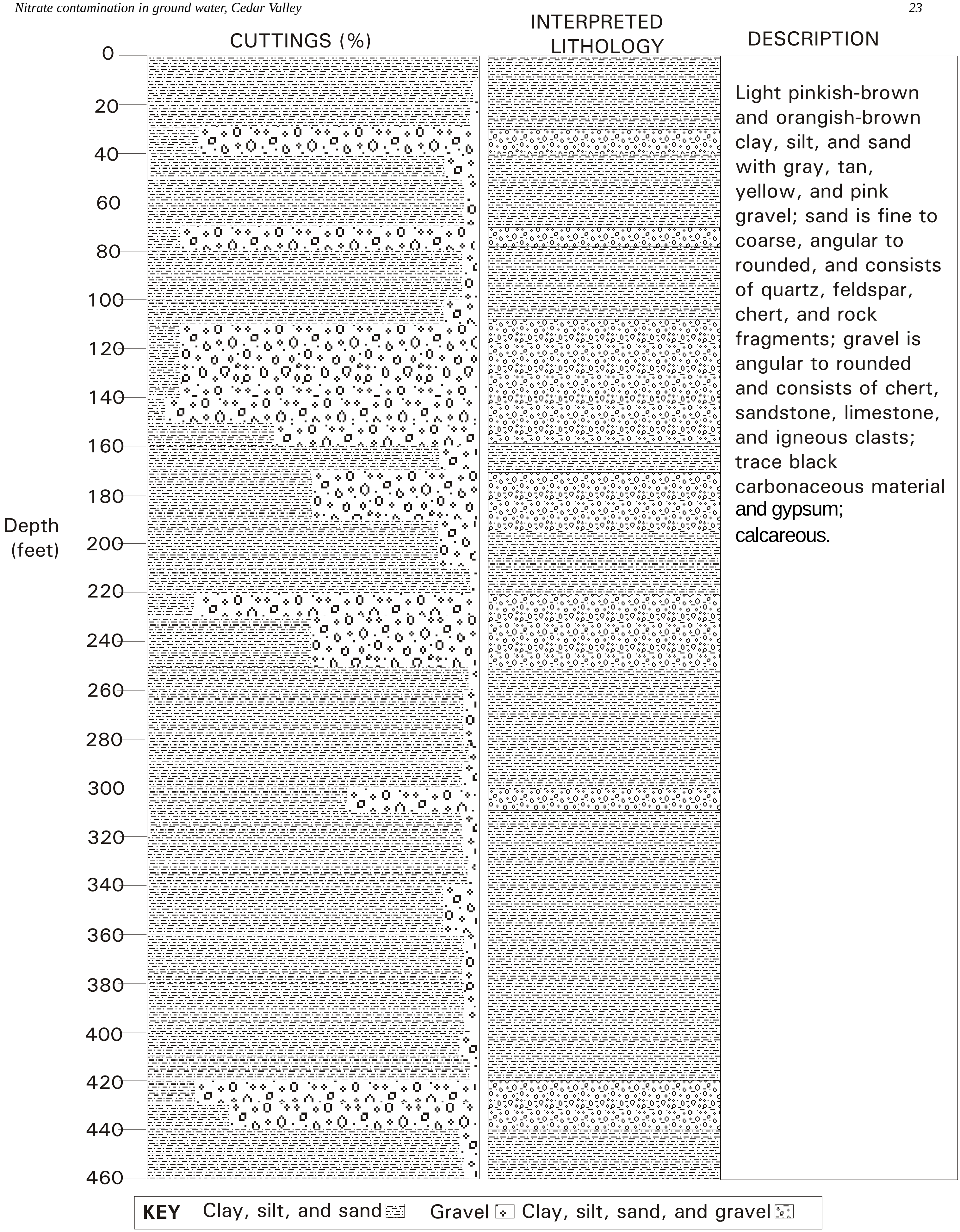

Figure 14. *Geologic log of water-well cuttings for well (C-35-11) 9abb.*

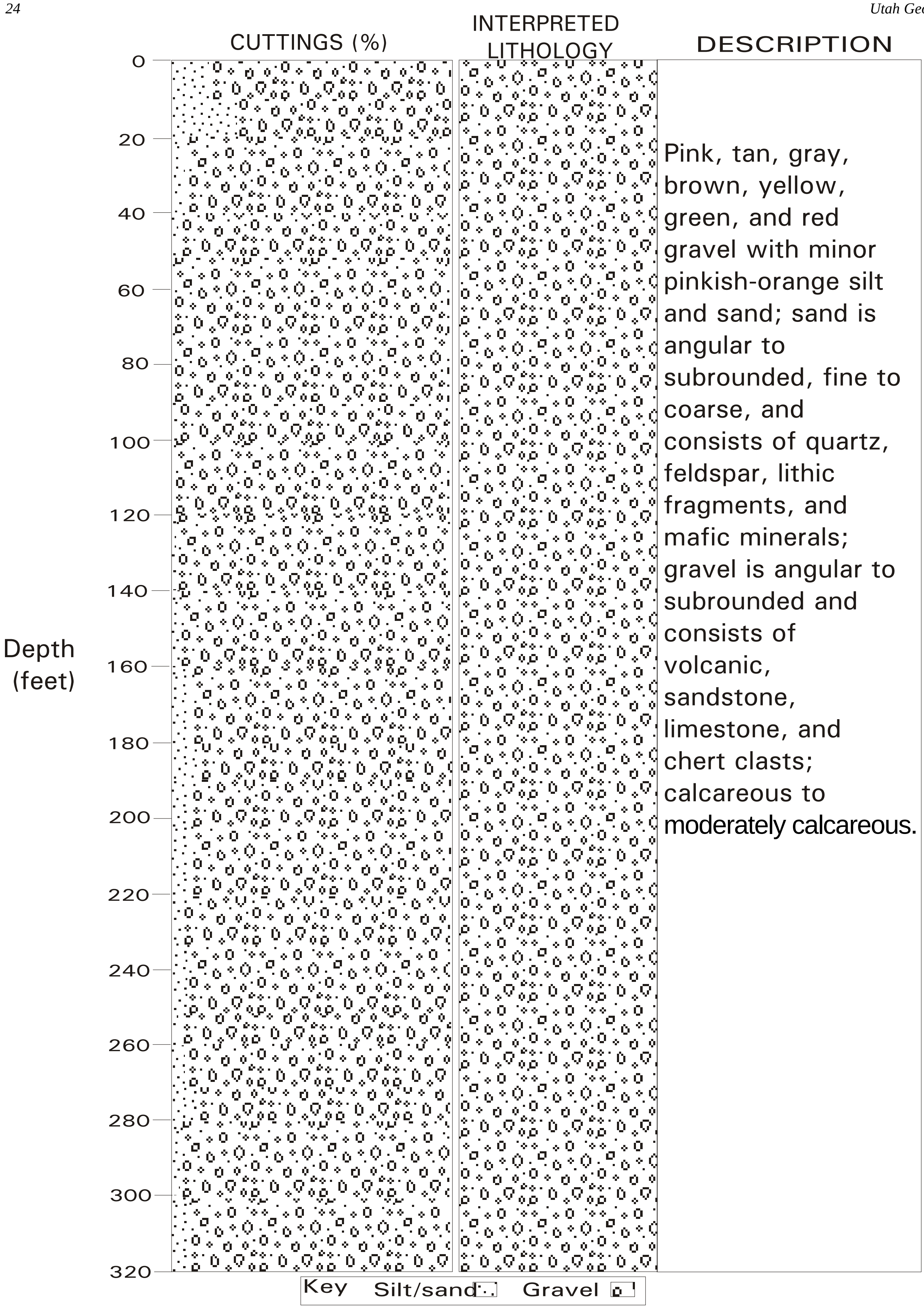

Figure 15. *Geologic log of water-well cuttings for well (C-35-11) 25bcd on Fiddlers Canyon alluvial fan.*

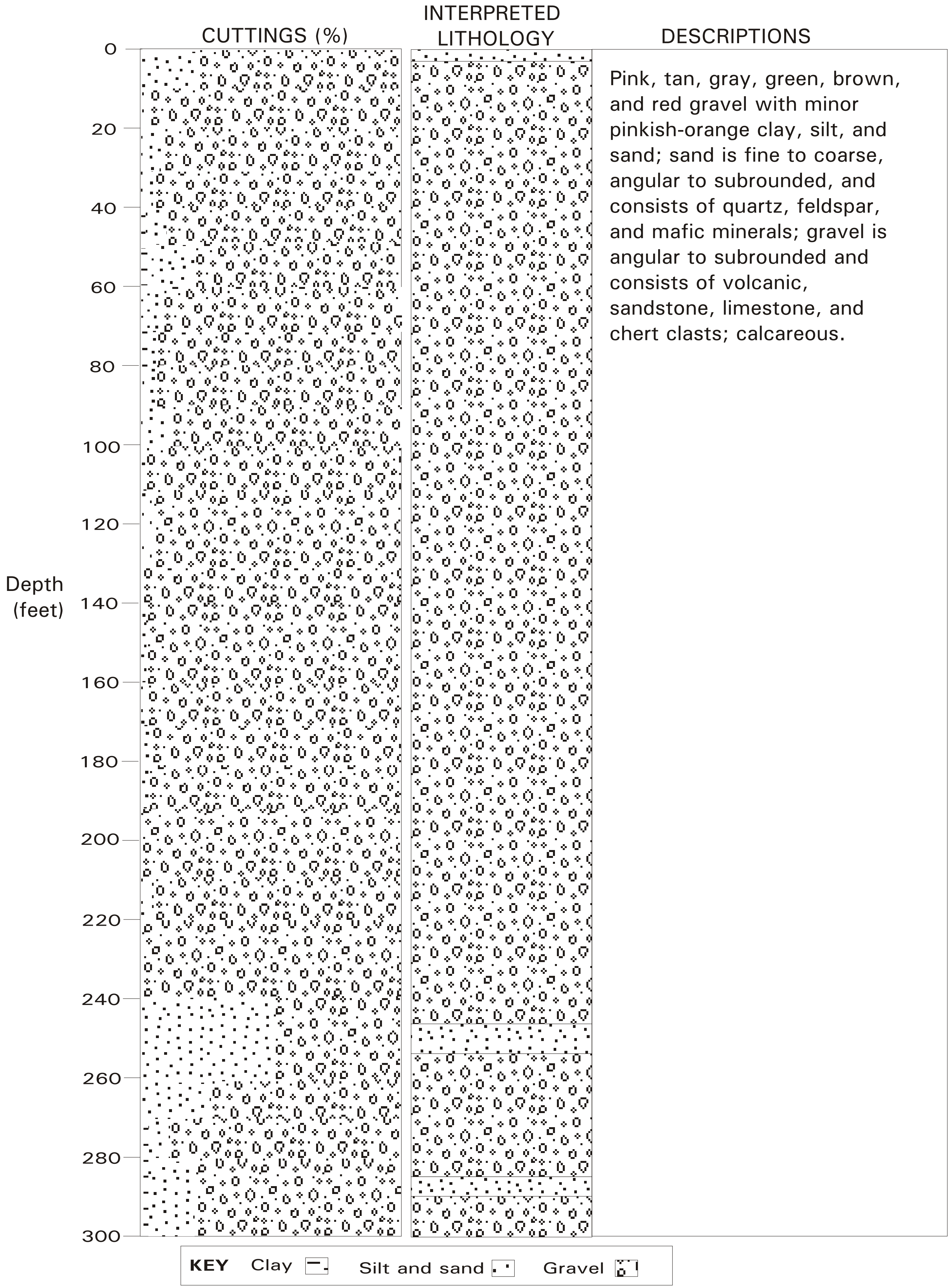

Figure 16. *Geologic log of water-well cuttings for well (C-35-11) 35bdb.*

tion of some wells tested during January, which had lower nitrate concentrations than at other times of the year. Nitrate concentration values obtained by SUU correspond to values from the state lab, indicating a consistency in nitrate concentration, lab analysis, and reporting. The range in nitrate concentrations for the 101 wells sampled during 1979-81 is 0.06 to 57.4 mg/L (figure 17), with an average of 7.59 mg/L (appendix C). Eight other wells in the same section (section 22) as the well having the highest nitrate concentration have an average concentration of 9.5 mg/L. These data are summarized in appendix C.

Depths of the water wells sampled from 1979-81 range from 96 to 800 feet (34-244 m) deep. Only one shallow well (less than 100 feet [30 m]) was sampled. Twenty-two wells are less than 300 feet (91 m) deep, and 41 wells are greater than 300 feet (91 m) deep (two were 800 feet [244 m] deep). There is no correlation between well or perforated interval depth and nitrate concentration (figure 18). For example, one 516-foot-deep (157 m) well with a perforated interval from 445 to 510 feet (136-155 m) has a nitrate concentration of approximately 13 mg/L (sampled multiple times with slight variations in nitrate concentration values), and shallower wells with depths of 240 and 255 feet (73 and 78 m) have nitrate concentrations of 2.7 and 0.19 mg/L, respectively; this indicates no correlation between nitrate concentration and depth. About half of the wells having driller's logs (30 of 63 well logs) have multiple-perforated intervals, which precludes identifying a nitrate source associated with a particular aquifer depth.

As stated above, two interpreted northeast-trending faults that do not offset Holocene deposits, the Enoch fault and the West Enoch fault, are situated near the eastern boundary and center of the study area, respectively. The percentage of high-nitrate wells (>10 mg/L) within the Enoch graben is over twice the percentage of high-nitrate wells west of the West Enoch fault, where wells yield ground water having lower average nitrate concentrations compared to water from wells east of this fault (figure 19). Water wells 1 mile (1.6 km) or more west of the West Enoch fault generally yield ground water with nitrate concentrations less than 5 mg/L; these wells are on the more distal portion of the alluvial fan, and perhaps penetrate basin-fill material deposited largely by Coal Creek to the northeast. In general, the more downgradient, distal wells have lower nitrate concentrations than upgradient wells situated at slightly higher elevations and nearer to the mouth of Fiddlers Canyon (figure 17), but there are many exceptions.

Nitrate Data From 1999

During June 1999, we resampled 21 of the water wells sampled in 1979-81 to evaluate possible trends in nitrate concentration over time (appendix C). Our new data show that nitrate concentrations range from 1 mg/L to 23.1 mg/L (figure 20), with an average of 8.1 mg/L and a median of 6.3 mg/L. Table 4 and appendix C summarize these data. More than half (13) of the wells sampled in 1999 have nitrate concentrations (including wells that had previous nitrate concentrations exceeding the ground-water quality standard) similar to concentrations measured in 1979-81 (table 4). Five wells have considerably lower nitrate concentrations, four of which previously exceeded the ground-water standard, but in 1999 were below it. Three wells have nitrate concentrations that exceed the ground-water quality standard by more than two times. In general, nitrate concentrations in water wells in the Enoch area appear to have remained relatively constant between 1979-81 and 1999 (figures 17 and 20). We collected two surface-water samples from Fiddlers Creek during this period; both samples contain less than 0.1 mg/L nitrate.

Nitrate Data From 1999 U.S. Geological Survey Well

In July of 1999 the U.S. Geological Survey drilled a 318-foot-deep (97 m) well on the Fiddlers Canyon alluvial fan (figure 11) in section 25, T. 35 S., R. 11 W., Salt Lake Base Line and Meridian. This well is upgradient from all known anthropogenic sources of nitrate. Ground water from the well yielded a nitrate value of 7 mg/L (J.L. Mason, U.S. Geological Survey, verbal communication, April 18, 2000).

GEOLOGIC NITROGEN SOURCES

Background

Contribution of bedrock nitrogen to nitrate concentrations in water has been recognized by many investigators (Mansfield and Boardman, 1932; Power and others, 1974; Boyce and others, 1976; Holloway and others, 1998). The following is a summary of types of rocks that have contributed nitrogen to nitrate concentrations in ground and surface water. Many of the rock types described below are also present throughout Cedar Valley including plutonic, volcanic, sedimentary rocks (for example, sandstone, limestone, shale, coal-rich deposits, evaporites, and playa-type deposits), alluvial sediments, and ore-related deposits. Much of the following discussion is extracted and summarized from Holloway (1999).

Ammonium-bearing aluminosilicate minerals have been identified in a number of geologic settings worldwide. Little is known regarding the influence of ammonium-bearing bedrock on soil and water quality (Holloway and Dahlgren, 1999). Nitrogen exists in rock as relict organic matter associated with sedimentary rock or as ammonium substituting for potassium in sedimentary, igneous, and metamorphic rock (Stevenson, 1962). Ammonium end-member silicate minerals include buddingtonite, tobelite, and ammonium muscovite and ammonium biotite. Buddingtonite, the ammonium end-member of potassium feldspar, has been identified in oil shales in Queensland, Australia (Loughnan and others, 1983), and in a clay unit of the Phosphoria Formation in Idaho (Gulbrandsen, 1974). Tobelite, an ammonium illite, was first identified in a Japanese clay deposit (Higashi, 1982). Ammonium micas may be formed directly from ammonium-bearing clay minerals (Voncken and others, 1987), or by ammonium substitution in pre-existing micas.

Sedimentary rocks that form in an organic-rich depositional environment can include nitrogen as residual organic matter or as ammonium minerals (Holloway and others, 1998). Ammonium minerals form during low-temperature ($T<150°C$ [$<302°F$]) hydrocarbon generation as identified in the Monterey Formation in southern California (Compton and others, 1992).

Ammonium concentrations in rock associated with hydrocarbons are a function of fluid migration and hydrocarbon maturation (Williams and others, 1989; Williams and

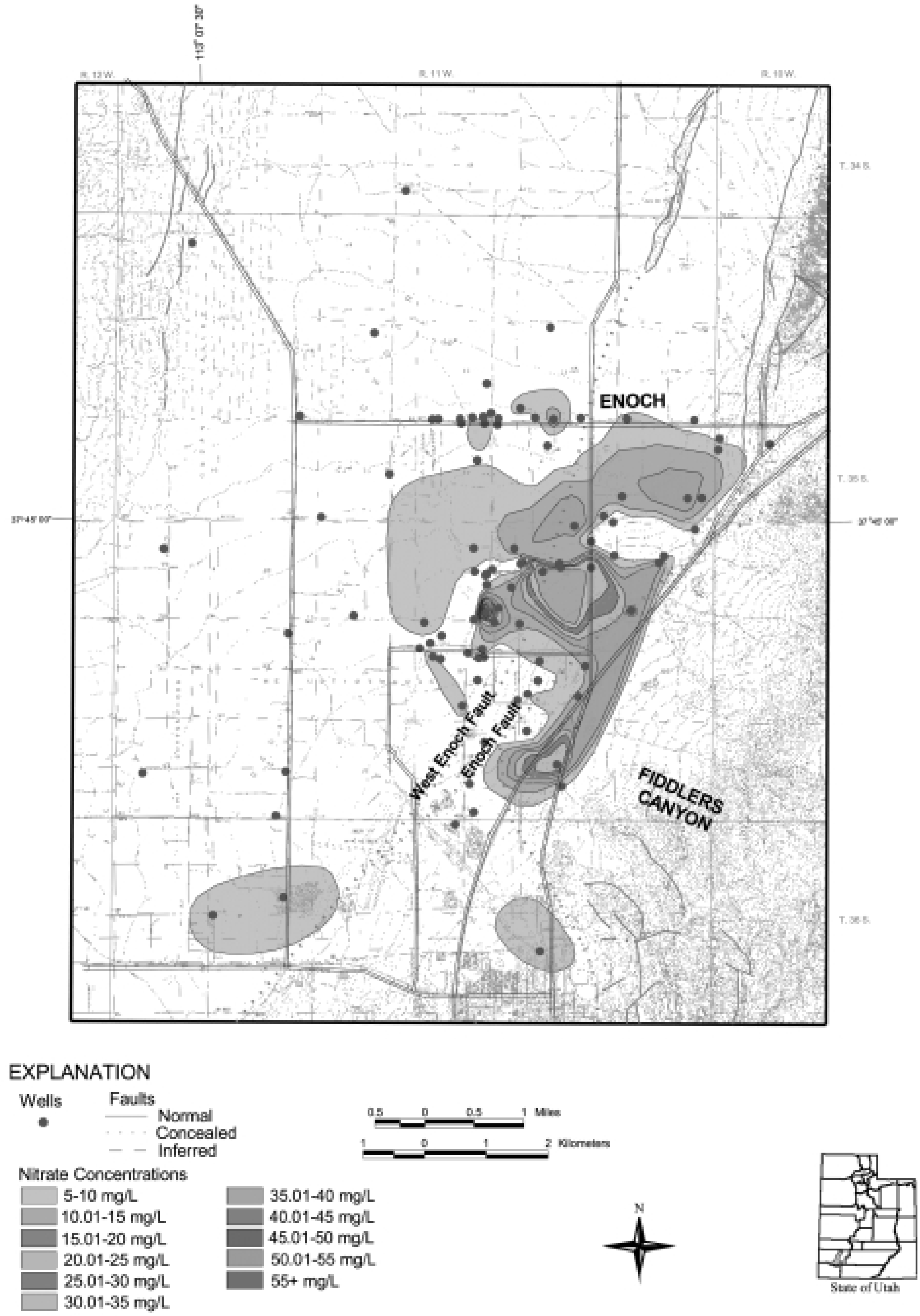

Figure 17. *Nitrate concentrations based on 1979-81 data for the Enoch area, Cedar Valley, Iron County, Utah.*

Table 4.
Summary of 1979-1981 and 1999 nitrate concentration data, Cedar Valley, Iron County, Utah.

Nitrate Concentration	Percent of Wells Sampled	
mg/L	**1979-1981**	**1999**
>10 mg/L	21	24
5 to 10 mg/L	18	38
<5 mg/L	44	38
<2 mg/L	17	9.5

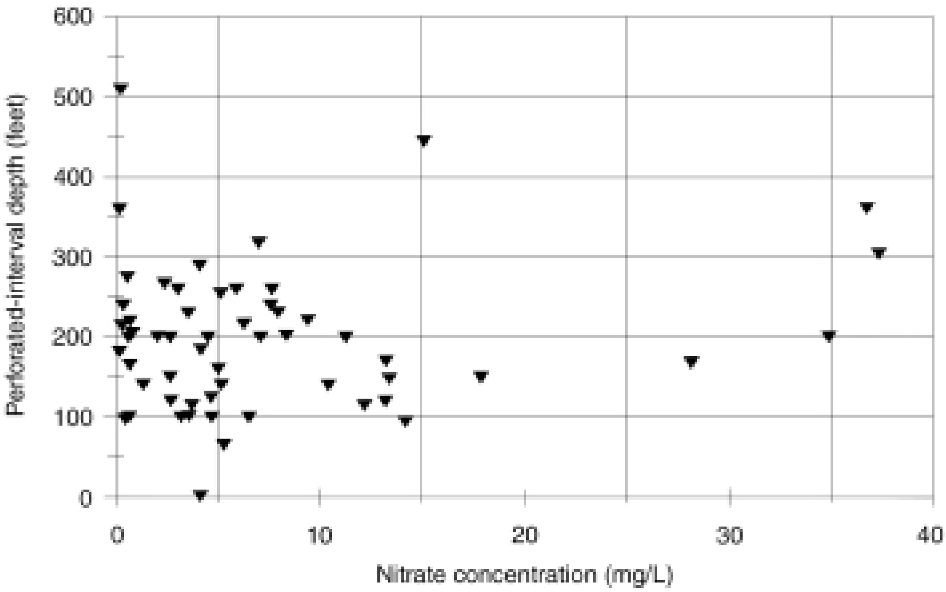

***Figure 18.** Nitrate concentration versus shallowest perforation depth for 56 wells sampled from 1979-81 in Cedar Valley, Iron County, Utah; correlation coefficient is 0.14.*

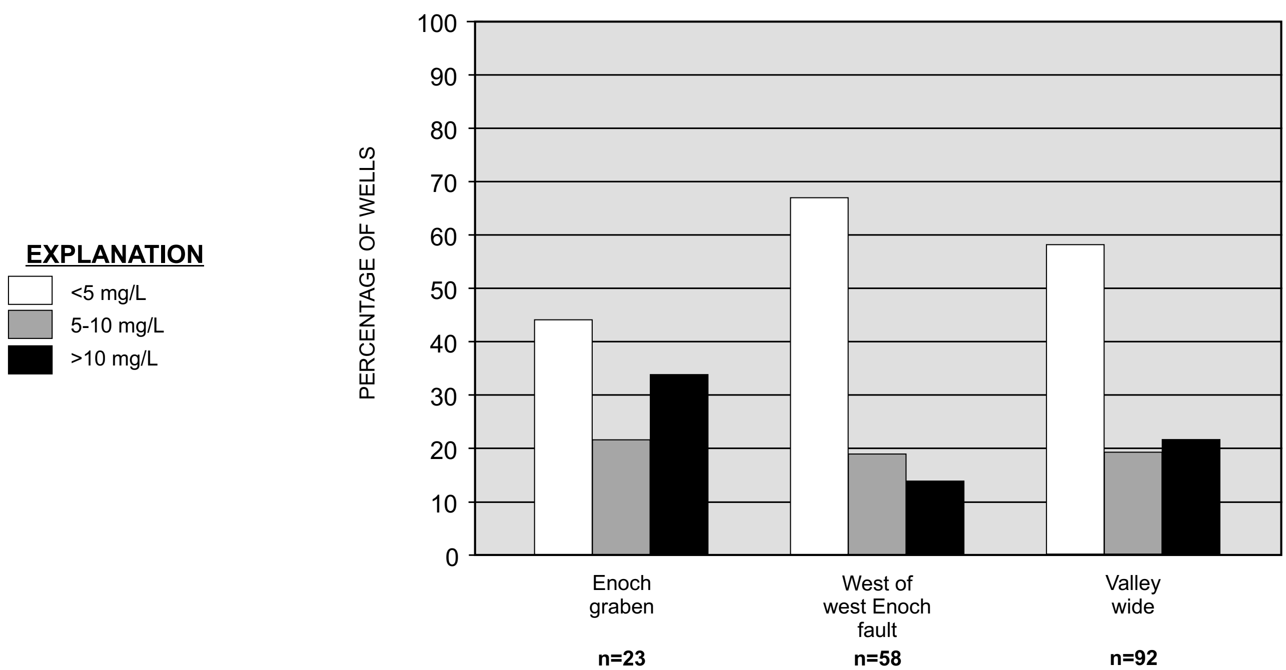

***Figure 19.** Percentage of wells having nitrate concentrations <5 mg/L, 5-10 mg/L, and >10 mg/L withing the Enoch graben, west of the West Enoch fault, and valleywide, Cedar Valley, Iron County, Utah, based on 1979-81 data. "**n**" refers to the number of wells sampled.*

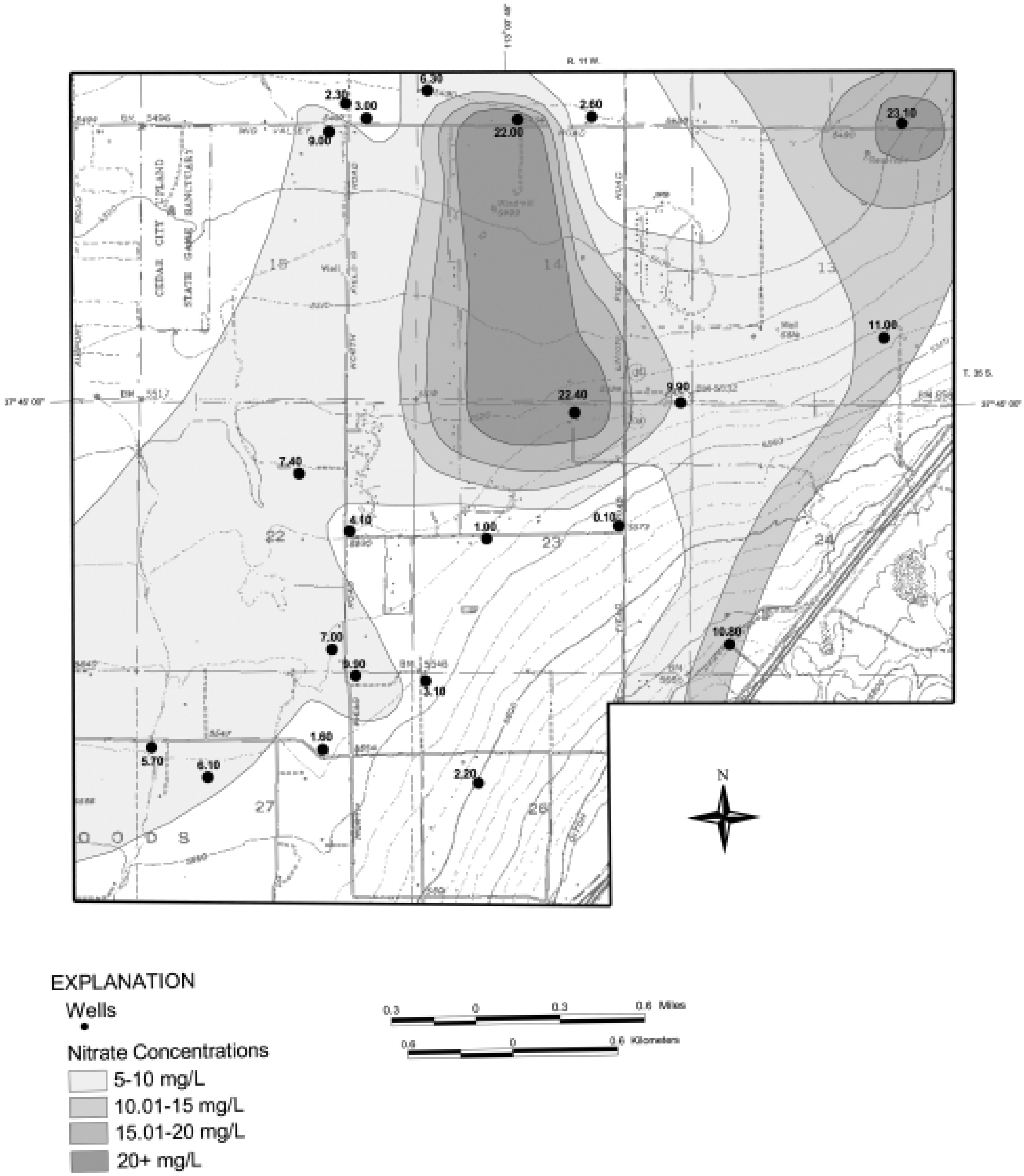

Figure 20. *Nitrate concentrations based on 1999 data for the Enoch area, Cedar Valley, Iron County, Utah.*

others, 1993). The accumulation of ammonium in illite above and below coal seams in the Cummock Formation of South Carolina indicates that nitrogen is transported from the organic matter in the coal seam to mineral sites where ammonium substitutes for potassium (Krohn and others, 1993). Coal deposits are a geologic regime with notable occurrences of geologic nitrogen. Ammonium-bearing illite is associated with low-grade metamorphic rocks associated with a coal seam in Pennsylvania (Juster and others, 1987). The presence of coal and hydrocarbons is an extreme example of organic matter serving as a source for ammonium in sedimentary rocks (Holloway, written communication, 1999). Authigenic ammonium-bearing feldspar in sandstones can also be used to infer the presence of organic matter during diagenesis (Ramseyer and others, 1993). Diagenesis refers to processes involving fluid and rock interactions, particularly sediments, that occur in the subsurface under particular temperature, pressure, and chemical conditions that may result in alteration of the original rock material and/or production of new minerals that form in place (authigenic) without undergoing metamorphism.

Ammonium minerals have been reported in low concentrations in igneous rock. Granites in central Spain have a mean concentration of 84 mg NH4+ per kg with the ammonium preferentially incorporated into biotite mica, then muscovite mica and potassium feldspar (Hall and others, 1996). Ammonium-bearing minerals in granitic rocks in England and Japan result from contamination of the magma by organic matter in the country rock (original rock) (Hall, 1988; Tainosho and Itihara, 1991a, 1991b).

High concentrations of ammonium associated with sediments or other organic matter sources can be incorporated into ore deposits (Williams and others, 1987). A study of hydrothermal systems in the Guyamas Basin off the California coast indicates ammonium will form aluminosilicate minerals associated with sulfides precipitated from sea water in the presence of organic matter (Von Damm and others, 1985). Ammonium-bearing alunite, indicative of acidic (pH<7) solutions at temperatures less than 100˚C (212˚F) and with high ammonium and low potassium in solution, is associated with hydrothermal systems in Nevada, California, Colorado, and Utah (Altaner and others, 1988). Buddingtonite in a Nevada ore deposit had up to 1,120 mg N per kg (Kydd and Levinson, 1986).

On a localized scale, release of nitrogen through weathering of nitrogen-bearing rock can potentially affect the quality of water and soil (Holloway and others, 1998). The term "geologic nitrogen" has been used to describe the source of high-nitrogen soils on alluvial fans in the San Joaquin Valley of California (Sullivan and others, 1979; Strathouse and others, 1980). Geologic nitrogen was recognized by Boyce and others (1976) as nitrogen associated with certain geologic formations of sedimentary origin. The contribution of rock from the Diablo Range to soil nitrogen in the western San Joaquin Valley was explored by Sullivan and others (1979). The chemical state of this nitrogen includes fixed and exchangeable ammonium sorbed to clay and organic surfaces, organic matter, and natronite, a sodium nitrate salt (Sullivan and others, 1979). The revegetation of coal mine spoils in the Canadian Rockies is facilitated by high nitrogen concentrations in the soils (Fyles and others, 1985). Holloway and others (1998) analyzed rocks in the Mokelumne River watershed, California, to determine if bedrock could be a source of stream-water nitrate and documented that metasedimentary rocks containing appreciable concentrations of nitrogen contributed a large amount of nitrate to surface waters. They concluded that nitrogen-rich rocks in the watershed, though occupying a small areal extent, had a greater influence on water quality than the areally extensive nitrogen-poor metavolcanic and plutonic rocks in the watershed.

Geologic nitrogen can also be affected by biological processes. Biochemical transformation can influence the release of nitrogen in bedrock to streams and ground water (Holloway and Smith, 2000). A study of nitrogen-rich strata in the Mancos Shale in a locally undeveloped region of western Colorado shows that denitrification of nitrate in stream water draining this unit occurs due to microbial transformation. In a 24-hour laboratory experiment, nitrate concentration in stream water decreased, with 65 percent of the total nitrogen removed (Holloway and Smith, 2000). The nitrogen released by weathering of the Mancos Shale to stream and ground water was consumed biochemically.

Natural nitrate is also associated with sediments typical of arid environments such as playa lake, alluvial-fan, and braided-stream deposits, primarily associated with atmospheric nitrogen. Rock-salt crusts in Chilean playas contain soda-niter (Stoertz and Ericksen, 1974) associated with oxidized ammonium salts that were subsequently leached and mobilized as nitrate in ground water. High nitrate concentrations in ground water from wells in Paradise Valley, Arizona, are attributed, in part, to natural sources of nitrate, possibly from ammonium chloride that was produced and trapped in volcanic rocks, and with subsequent weathering, leaching, and oxidization, eventually was transported as nitrate by ancient streams (Silver and Fielden, 1980). Nitrate may have concentrated in abandoned channels of the braided-stream system, which became evaporation sites, leaving behind nitrate residue (Silver and Fielden, 1980). Nitrate exists as water-soluble salts in zones below leached soils in evaporative playa environments in southeastern California, and is associated with Tertiary playa deposits and beds of saline and gypsiferous shale, sandstone, and limestone (Noble, 1931).

Potential Sources of Geologic Nitrogen in Cedar Valley

Based on literature regarding geologic nitrogen and its contribution to high nitrate concentrations in water, we selected several rock types and sediments in Cedar Valley for laboratory analysis of nitrogen content (plate 1, appendix A). Below, we outline and describe geologic units located in the surface-water drainage basin and/or the ground-water recharge area for the Enoch study area and justify our selection of these rocks as potential nitrate contributors. The specific chemical composition of these rocks is unknown. We consider those rock units that showed measurable amounts of nitrogen to be potential sources of geologic nitrogen while we assume that those rocks that showed negligible quantities of nitrogen are not. However, because we have not rigorously tested numerous rock samples to document any specific quantifiable amount of nitrogen, any conclusions regarding sources of geologic nitrogen in the study area contributing nitrate to ground water are preliminary.

Potential geologic sources of natural nitrate in Cedar Valley include: (1) the coal seams and organic-rich siltstone layers in Cretaceous sandstone units, including mine-related dumps or spoil piles associated with them, (2) Triassic gypsiferous sedimentary rocks, (3) Tertiary volcanic rocks, (4) hydrothermally altered rocks associated with faults, and (5) Recent sediments (including stream and playa deposits). All of these potential sources of geologic nitrogen are present in the Enoch area or the recharge area east of Enoch.

There are two potential sources of geologic nitrogen in the Cretaceous Straight Cliffs Formation: (1) relict organic matter, and (2) diagenetically induced substitution of ammonium ions for potassium ions in silicate minerals, especially micas. Common relict organic matter in the Straight Cliffs Formation includes coal, chips of charcoal, carbonized twigs, branches, leaves, and pollen spores (Doelling and Davis, 1989). Substitution of ammonium for potassium ions is common in silicate minerals, such as feldspar and mica, or in clay minerals (hydrous aluminum silicates), including illite and smectite. Diagenetic minerals, such as dolomite, pyrite, and aluminosilicate minerals with high exchangeable- or fixed-NH_4^+ contents are typically produced by the degradation of organic matter (Compton, 1988) associated with organic-rich marine rocks (Compton and others, 1992). If present, nitrogen-rich minerals in the Straight Cliffs Formation may have formed under reducing conditions, with illitization of clays enhanced in NH_4^+ from nitrogen-rich organic layers (at particular pressure/temperature conditions during burial diagenesis and subsequent faulting). Thus, nitrogen from the Straight Cliffs Formation could result from either subsequent oxidation of the diagenetically produced ammonium to nitrate, or from the release of nitrogen from organic-rich layers, such as coal seams.

Gypsum-rich deposits of shale, limestone, and sandstone of Mesozoic units (Moenkopi and Carmel Formations) may also contain nitrate salts that formed in playa- or sabkha-like environments. These nitrate salts could be leached into ground and surface water.

Leaching of volcanic rocks may also contribute geologic nitrogen from the oxidation of ammonium-containing minerals. Ammonium compounds that may be present in igneous rocks would likely result from incorporation of nitrogen compounds present in country rock during volcanism. High nitrate concentrations in ground water from wells in Paradise Valley, Arizona, are attributed, in part, to natural sources of nitrate; this nitrate may be derived from ammonium chloride that was produced and trapped in volcanic rocks, then leached and oxidized during subsequent weathering, and eventually transported in ground water as nitrate (Silver and Fielden, 1980). Tertiary volcanic rocks in the study area are present at the southern terminus of the Red Hills and a small outcrop along and just east of Interstate 15. The Miocene Leach Canyon Formation, the lower Narrows Tuff, and the upper Table Butte Tuff Members may contain ammonium compounds that could potentially leach into ground water.

Hydrothermal alteration may produce ammonium-rich minerals by replacement of potassium by ammonium in micas and felspar, and by the production of tobelite or buddingtonite. Nitrogen from these minerals, if present, could then be incorporated into ground water flowing along the Enoch or West Enoch faults. Data from our study indicate elevated nitrate concentrations in ground water for wells either east or within about a mile to the west of the West Enoch fault zone relative to ground water from wells farther west of the West Enoch fault; nitrate concentrations in almost all of the samples for wells more than a mile (1.6 km) downgradient from the West Enoch fault zone are below 5 mg/L.

Recent deposits, such as abandoned braided ephemeral stream beds on the Fiddlers Canyon alluvial fan, are another potential source of geologic nitrogen. In arid environments, nitrate may be concentrated in water-soluble salts at evaporation sites within abandoned channels of braided stream systems, leaving behind a soluble nitrate-rich residue.

Description of Stratigraphic Units/Sites Sampled for Potential Geologic Nitrogen

The most plausible geologic nitrogen sources near Enoch include sedimentary deposits rich in coal and gypsum, volcanic tuffs and ash flows, possible hydrothermal-related activity along fault zones, and modern ephemeral streams. We sampled rocks and soils in these types of deposits in the Enoch area to determine their potential as natural source(s) of geologic nitrogen (plate 1).

Mesozoic rocks situated in the recharge area in both Fiddlers Canyon and Coal Creek Canyon, and Tertiary volcanic rocks that have been offset by normal faults along the eastern margin of Cedar Valley may be potential sources of geologic nitrogen (plate 1). Descriptions of rock units and vertical profiles of local stratigraphic horizons where we collected samples for nitrogen analysis are as follows; note that measurements in the field were taken using a metric tape so metric numbers are presented first. Steeply westward-dipping rocks of the Cretaceous Straight Cliffs Formation dominate the lower reaches of Fiddlers Canyon. The dominant rock types at the mouth of Coal Creek are siltstone, mudstone, and gypsiferous deposits of the Triassic Moenkopi Formation. Faulted Tertiary volcanic rocks exist just west and north of the mouth of Fiddlers Canyon. Water-well cuttings from the Fiddlers Canyon alluvial fan are likely representative of modern and ancient alluvial deposits.

We collected four rock samples for nitrogen analysis from a 5.5-meter-thick (18 ft) section of a marine sandstone sequence in the lower member of the Straight Cliffs Formation (plate 1). The basal part of this section consists of a 0.75-meter-thick (2.5 ft), brownish-black, micaceous, organic-rich layer containing oyster fragments and exhibiting wavy bedding (figure 21). This unit is overlain by two separate and distinct sandstone intervals separated by a thin siltstone/mudstone interval (figure 22). The lower sandstone interval is 2.5 meters (8.2 ft) thick and consists of weathered, grayish-yellow, fine- to medium-grained, calcareous sandstone containing whole and fragmented oyster-shell fossils. Oyster-shell content increases up section. The outcrop displays faint cross-stratification and a channel-like geometry with minor epsilon cross-strata up section. This interval is conformably overlain by a 0.5- to 0.75-meter-thick (1.6-2.5 ft) contorted to thinly laminated siltstone/mudstone interval that grades laterally into a brownish-black, organic-rich layer with wavy bedding. This layer is overlain by a massive 1.5-

Figure 21. *Organic-rich layer of the Cretaceous Straight Cliffs Formation up Fiddlers Canyon.*

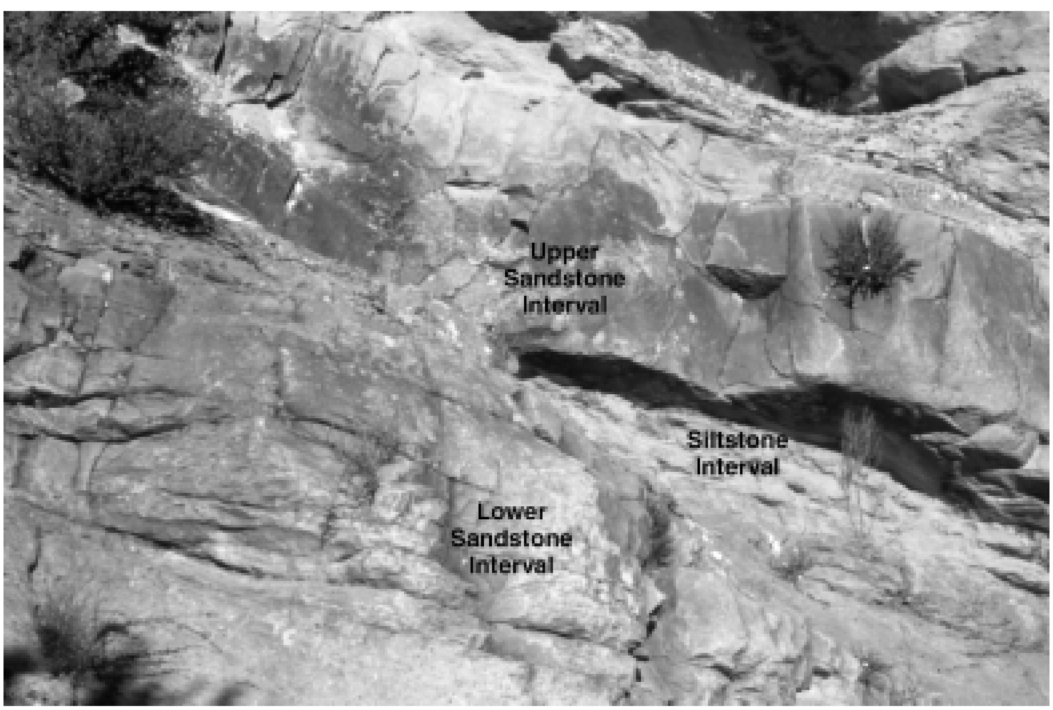

Figure 22. *Sandstone of the Cretaceous Straight Cliffs Formation up Fiddlers Canyon, showing sandstone interval separated by a thinner siltstone/mudstone interval. Vertical scale is about 15 feet (4.6 m).*

meter-thick (4.9 ft), calcareous, fine grained sandstone interval that exhibits faint planar cross-stratification and contains no fossils. Laterally, this channel-like interval grades into thinner fine-grained sandstone strata interbedded with finer grained sandstone and siltstone.

Because some of the water wells north and west of the Coal Creek alluvial-fan area were also high in nitrate, we collected samples from gypsum-rich units near the mouth of Cedar Canyon (plate 1) to determine whether natural nitrogen was present. We sampled a nonmarine, possibly sabkha-like section, of the upper part of the Triassic Moenkopi Formation (Averitt and Threet's [1973] undivided upper map unit) up Coal Creek Canyon (figure 23). The outcrop is in a faulted strike valley situated perpendicular to the main east-west drainage of Coal Creek. There, the upper part of the Moenkopi Formation we describe is approximately 6 meters (19.7 ft) thick. A 2.5-meter-thick (8.2 ft) basal unit consists of red, finely laminated, intercalated siltstone, mudstone, and gypsum with individual sets ranging from a few millimeters up to 0.5 centimeter thick (a few hundredths of an in. to 0.4 in.). This interval is overlain by two 1-meter-thick (3.3 ft), fissile, gypsiferous layers separated by 1.5 meters (4.9 ft) of featureless red slope material, likely composed of mudstone (figure 24). In possible fault contact with this unit is an overlying grayish-white and red gypsiferous unit.

We sampled the Leach Canyon Formation just east of Interstate 15 (plate 1) from a poorly exposed fault contact between the more friable Leach Canyon Formation and well-indurated Isom Formation. There, the Leach Canyon Formation consists of poorly welded pink tuff with variable-sized clasts of pumice and felsic volcaniclastic material, and is in fault contact with the underlying, purple, crystal-poor welded tuff of the Isom Formation.

We also tested water-well cuttings from two water wells in the Enoch area for natural nitrate. The well logs are described in a previous section, and appendix B includes detailed descriptions of the intervals where the samples were obtained. We analyzed two samples from (C 35-11)9abb, one from the 54- to 60-foot (16- to 18-m) interval and one from the 150- to 160-foot (46- to 49-m) interval. We analyzed one sample from the well (C-35-11)1bbb, situated near the West Enoch fault, at the 40- to 50-foot (12- to 15-m) interval.

Results

We analyzed nine rock and soil samples from Cedar Valley for nitrogen content (appendix A) to determine their potential as possible natural geologic nitrogen sources. We tested water-well cuttings from two different water wells located in the Enoch area and analyzed the sediment from 10-foot (3 m) depth intervals (two different depth intervals from well C-35-11)1bbb) (appendix B). None of the well-cuttings samples analyzed have significant concentrations of nitrogen (appendix A) relative to water-quality concerns. Only one sample from (C-35-11)9abb has measurable concentrations of nitrogen (40 ppm) (appendix A).

Volcanic tuff of the Leach Canyon Formation, sampled adjacent to a mapped fault zone (9 1-A), has no measurable nitrogen and very low carbon (appendix A), consistent with its volcanic origins. The gypsiferous sample (A-1-1) of the upper red member of the Moenkopi Formation obtained from Coal Creek Canyon has measurable nitrogen (40 ppm) (appendix A), but at concentrations too low to affect ground-water quality.

Four samples obtained from the lower member of the

Figure 23. *Upper member of the Triassic Moenkopi Formation in Coal Creek Canyon.*

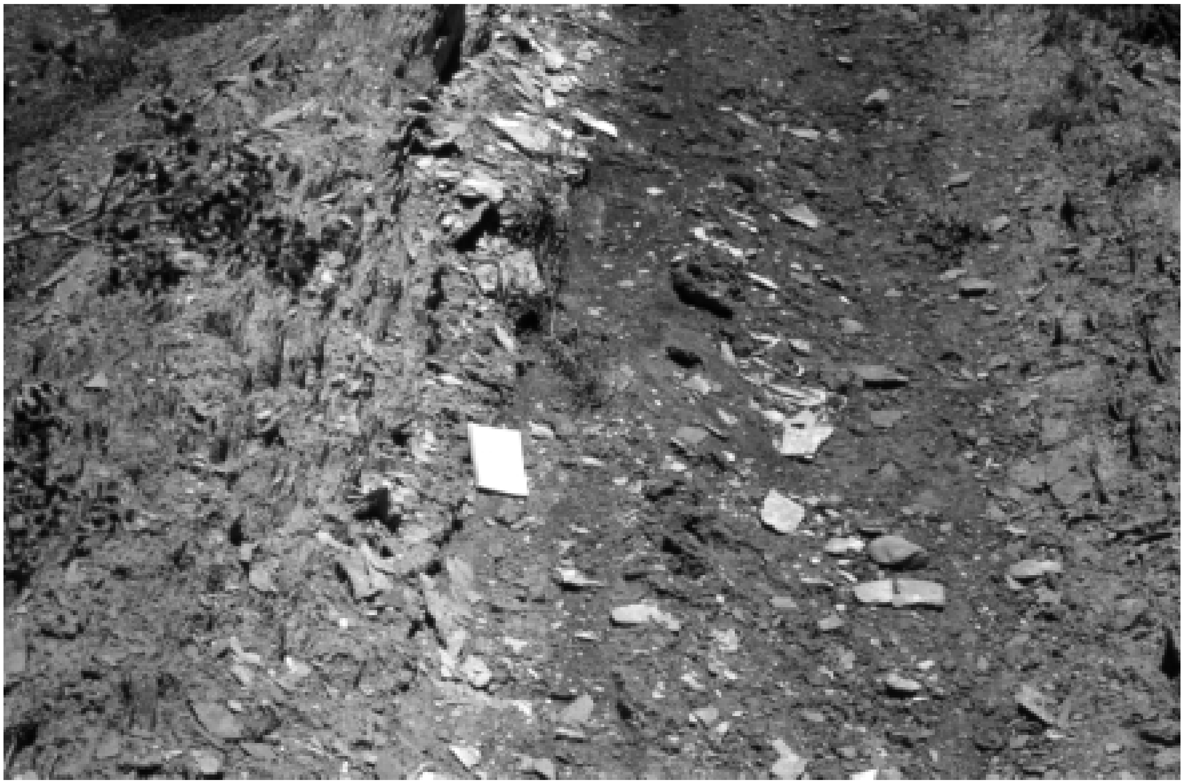

Figure 24. *Red mudstone encased between gypsiferous units of the upper member of the Moenkopi Formation in Coal Creek Canyon.*

Cretaceous Straight Cliffs Formation up Fiddlers Canyon were analyzed for nitrogen content (appendix A). A fossiliferous oyster-shell rich sandstone sample (10798C) has a low concentration of nitrogen (60 ppm), and the soil mantling an organic-rich siltstone layer (10798B) has no measurable nitrogen (appendix A). Two samples from strata within the same section of rocks, an organic-rich carbonaceous siltstone (10798D; sample analyzed twice) and a fine-grained calcareous sandstone (10798A), have higher concentrations of nitrogen. These concentrations of nitrogen, between 530 and 670 ppm N (appendix A), indicate they may be a source of nitrogen that could leach into ground water and be converted to nitrate.

CONCLUSIONS AND RECOMMENDATIONS

Many water wells in the Enoch area of Cedar Valley have yielded ground-water samples that contained relatively high nitrate concentrations. The persistently high nitrate values from the Enoch area are difficult to explain solely by past land-use trends. Other parts of the valley have experienced similar land uses, but have lower nitrate concentrations in ground water; for instance, wastewater disposal in Cedar City was once primarily accomplished using septic-tank systems.

Overall nitrate concentrations in ground water in the Enoch area remain generally consistent with data collected during 1979-81, despite Enoch's conversion to a sanitary sewer system in 1995. Ground water from some wells have maintained background levels of between 7 and 8 mg/L nitrate for decades. This is somewhat surprising, especially considering that similar rural areas in other Utah basins have average background nitrate concentrations around 2 mg/L (Lowe and Wallace, 1997; Wallace and Lowe, 1997, 1999). In addition to nitrate related to human activity/land-use practices (such as the use of septic-tank systems and residential and agricultural fertilizer application), we consider natural geologic nitrate to be one viable source for the persistent, anomalously high concentrations of nitrate in ground water in the Enoch area (Wallace and Lowe, 2000).

Nitrogen-bearing rocks of the Cretaceous Straight Cliffs Formation may contain ammonium-rich minerals and organic nitrogen compounds that can be oxidized and subsequently mobilized as nitrate in ground water. This formation may contain sufficient nitrogen to contribute to elevated nitrate levels in ground water under geochemical conditions conducive to nitrification. However, we recognize that the limited data available to us in this study are insufficient for making even qualitative judgements regarding the amount of geologic nitrogen in the Straight Cliffs Formation in Fiddlers Canyon. We believe many additional samples from Straight Cliffs Formation strata need to be collected and analyzed for nitrogen before attributing geologic nitrogen as a primary source of nitrate in ground water in the Enoch area. Nevertheless, historically high nitrate levels in the Enoch area indicate that some condition prevails that differs from other areas in Cedar Valley; the presence of an ephemeral, debris-flow-prone stream eroding into the strata of the Straight Cliffs Formation here is unique within this valley.

Nitrogen-bearing sediments eroded from the Straight Cliffs Formation in Fiddlers Canyon and deposited as debris within the alluvial fan at the mouth of the canyon are a possible source of geologic nitrogen. Isolated and sporadic pods of nitrogen-bearing material may have been distributed via braided-stream channels which shifted locations on the alluvial fan as it filled the Cedar Valley basin in the Enoch area. This may explain the variable distribution of the high nitrate-concentration wells completed in the alluvial-fan deposits at various geographic locations and at various depths in the Enoch area. The West Enoch fault may have acted in part as a barrier to deposition, causing debris from Fiddlers Canyon to primarily fill the Enoch graben, somewhat controlling the westward extent of much of the Straight Cliffs Formation detritus; this may be reflected in the distribution of wells yielding ground water with relatively high nitrate values in the Enoch area.

Evidence supporting our hypothesis that natural nitrogen may be an additional source of nitrate in ground water in the Enoch area includes: (1) the overall negligible annual and seasonal changes in nitrate concentrations since the early and mid 1900s (since which time both population and land-use practices have changed), (2) high nitrate concentrations in ground water tapped by deep wells with deep-perforated intervals as well as shallow ones, (3) an anomalously high nitrate concentration in water from a well recently drilled on the Fiddlers Canyon alluvial fan upgradient from all past and present septic-tank systems, and in an area that is presently served by a sanitary sewer system, and (4) the lack of significant change in nitrate concentrations since the establishment of a sanitary sewer in the Enoch area coupled with the low background nitrate concentration (0.6 mg/L vs. 7 mg/L in the Enoch area) in the Mid Valley Estates area, downgradient from Enoch, where septic-tank systems continue to be used for wastewater disposal. Some strata in the Straight Cliffs Formation are likely one source of geologic nitrogen. Other areas in Cedar Valley that do not have these same strata in their drainage basins have lower background levels of nitrate concentration in ground water (Lowe and others, 2000), which further supports our conclusion that geologic nitrogen is one possible source of nitrate in ground water in the Enoch area. These lines of reasoning, however, do not preclude human input, such as leaking septic systems and fertilizer, as sources of nitrogen.

In order to corroborate geologic nitrogen as a source of nitrate in ground water in the Enoch area, isotopic analysis for nitrogen should be conducted for nitrogen-bearing units in the Straight Cliffs Formation and compared with isotopic analyses of high-nitrate ground water to check for similarities in isotopic signature. For those rock samples containing nitrogen, leachate experiments should be conducted to determine whether they can contribute nitrogen into the ground-water system. Additional rock samples should be obtained from different strata in the Straight Cliffs Formation to determine if nitrogen-bearing units are areally extensive. Finally, water from affected wells should be analyzed for pharmaceuticals and caffeine to verify whether anthropogenic sources also contribute nitrate to ground water in the region.

ACKNOWLEDGMENTS

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APPENDICES

APPENDIX A

Nitrogen and Carbon Data for Rock, Soil, and Sediment Samples

Field Methods

We collected rock, soil, and water-well cuttings samples for nitrogen-content analysis. Fresh rock samples were obtained by cutting or digging through the weathered zone. We collected samples having minimal exposure to the atmosphere or contact with ephemeral surface water. We obtained soil samples by digging through well-developed A horizons. Water-well cuttings were obtained from recently drilled water wells; samples were collected at 10-foot (3 m) intervals and stored in sample bags. We collected a total of six rock samples (four from Fiddlers Canyon, one from Coal Creek Canyon, and one from a fault zone west of Fiddlers Canyon near Interstate 15), three samples of water-well cuttings from unconsolidated deposits in the Enoch area, and one soil sample from Fiddlers Canyon for laboratory analysis.

Laboratory Methods

JoAnn Holloway, University of California at Davis, performed laboratory analysis for nitrogen and carbon as follows. Rock samples were cut and any weathering rinds removed. Soil and rock samples were sonicated with 5 percent hydrogen peroxide to remove organic matter associated with lichens and binding organic matter in soils. Roots present in soil samples were removed by flotation. Samples were then crushed by shatterbox in a tungsten-carbide chamber. The powders were loaded into tin boats and pyrolyzed at 1,868 °F (1020 °C) to measure nitrogen using a Carlo-Erba elemental analyzer. Values for carbon were simultaneously measured and are included with the data (table A-1). Both carbon and nitrogen were analyzed to determine whether samples have been contaminated by applying the Redfield ratio (C/N) (table A-1). The detection limit for nitrogen using this instrument is 40 ppm N. An external standard, MOK18, was run with the samples to ensure the validity of values produced by the instrument. The values for MOK18 are within an acceptable range for these samples.

Table A-1.
Nitrogen and carbon concentrations in rock and soil samples, Cedar Valley, Iron County, Utah.
Sampling locations are shown on plate 1.

Index	Sample	Description	Sample Type	N (ppm)	C (ppm)
standard	MOK18	—	—	1,260	8,910
1	10798A	Fiddlers Canyon; Straight Cliffs Formation	calcareous sandstone	670	50,210
2	10798B	Fiddlers Canyon; soil horizon developed on Straight Cliffs Formation	silty sand	0	41,740
3	10798C	Fiddlers Canyon; Straight Cliffs Formation	fossiliferous sandstone	60	50,040
4	10798D	Fiddlers Canyon; coal seam with gypsum within Straight Cliffs Formation	carbonaceous siltstone	530	72,340
4	10798D	Fiddlers Canyon; coal seam with gypsum within Straight Cliffs Formation	carbonaceous siltstone	570	72,540
5	9-1-A	Fault zone near I-15 west of Fiddlers Canyon; Leach Canyon Formation	tuff	0	290
6	A-1-1	Coal Creek Canyon; Moenkopi Formation	gypsum	40	62,930
7	73-143	Water well (C-35-11)9abb; basin fill at depth of 40-50 feet	sandy silt	40	50,900
8	73-3115	Water well (C-35-11)1bbb; basin fill at depth of 54-60 feet	sandy silt	0	11,830
9	73-3115	Water well (C-35-11)1bbb; basin fill at depth of 150-160 feet	silty loam	0	35,070
standard	MOK18	—	—	1290	9,360

APPENDIX B

Description of Well-Log Cuttings

Water-well drillers obtained well cuttings at 10-foot (3 m) sampling intervals. We analyzed the cuttings using a 40x power binocular microscope to estimate percentage of sedimentary material, including clay, silt, sand, and gravel. We described sand and gravel clasts according to mineral and/or lithology type. Abbreviations: tr = trace, MCS = maximum clast size, ACS = average clast size.

PERCENTAGE LOG OF WATER-WELL CUTTINGS

UTAH GEOLOGICAL SURVEY

DWRi Appropriation #: 73-3115 (a22218) — Well Owner: L. Jonsson
Location: (C-35-11)1bbb, Iron County, Utah
Driller: Grimshaw & Sons — Geologist: Janae Wallace, 9/17/98

DEPTH RANGE (feet)		PERCENTAGES unconsolidated		COMMENTS
		clay/silt/ sand*	gravel	
54	60	10	90	Light reddish-tan and gray gravel with minor light brownish-orange clay, silt, and very fine to coarse sand; sand is angular to rounded and consists of quartz, feldspar, mafic minerals, chert, and rock fragments; gravel is angular to subangular and consists of volcanic clasts with minor sandstone, chert, and limestone; MCS is 1.5 cm, ACS is 0.5 cm; calcareous
60	100	0	0	No sample
100	110	95	5	Light brownish-orange clay, silt, and very fine to medium sand with minor gravel; sand is angular to subrounded and consists of quartz, feldspar, mafic minerals, chert, and rock frag ments; gravel is angular and consists of volcanic clasts with minor sandstone, chert, and limestone; MCS is 1.5 cm, ACS is 1.5 cm; calcareous
110	120	97	3	As above, but MCS is 1.5 cm, ACS is 1.5 cm
120	130	95	5	As above, but MCS is 2.5 cm, ACS is 1 cm
130	140	95	5	As above, but MCS is 0.5 cm, ACS is 0.5 cm
140	150	95	5	As above, but MCS is 1 cm, ACS is 1 cm
150	160	100	tr	As above
160	170	99	1	As above, but MCS is 0.5 cm, ACS is 0.5 cm
170	180	99	1	As above, but MCS is 1.5 cm, ACS is 0.3 cm
180	190	100	tr	Light brownish-orange clay, silt, and very fine to medium sand with minor gravel; sand is angular to subrounded and consists of quartz, feldspar, mafic minerals, chert, and rock frag ments; gravel is angular and consists of volcanic clasts with minor sandstone, chert, and limestone; calcareous
190	200	99	1	As above, but MCS is 0.5 cm, ACS is 0.5 cm
200	210	99	1	As above, but MCS is 1 cm, ACS is 1 cm
210	220	99	1	As above, but MCS is 1.5 cm, ACS is 0.5 cm
220	230	99	1	As above, but MCS is 1 cm, ACS is 1 cm
230	240	99	1	As above, but MCS is 1 cm, ACS is 1 cm
240	250	100	tr	As above
250	260	100	tr	As above
260	270	99	1	As above, but MCS is 0.5 cm, ACS is 0.5 cm
270	280	99	1	As above, but MCS is 1 cm, ACS is 0.5 cm
280	290	99	1	As above, but MCS is 1.5 cm, ACS is 0.5 cm
290	300	90	10	As above, but MCS is 1 cm, ACS is 0.3 cm
300	310	97	3	As above, but MCS is 1 cm, ACS is 1 cm
310	320	60	40	As above, but MCS is 1.5 cm, ACS is 0.5 cm
320	330	85	15	As above, but MCS is 1 cm, ACS is 0.5 cm
330	340	98	2	As above, but MCS is 1 cm, ACS is 1 cm
340	350	98	2	As above, but MCS is 1 cm, ACS is 1 cm
350	360	98	2	As above, but MCS is 1 cm, ACS is 1 cm
360	370	99	1	As above, but MCS is 1 cm, ACS is 0.5 cm

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DEPTH RANGE (feet)		PERCENTAGES unconsolidated		COMMENTS
		clay/silt/ sand*	gravel	
370	380	100	tr	Light brownish-orange clay, silt, and very fine to medium sand with minor gravel; sand is angular to rounded and consists of quartz, feldspar, mafic minerals, chert, and rock frag ments; gravel is angular to subrounded and consists of volcanic clasts with minor sandstone, chert, and limestone; calcareous
380	390	97	3	As above, but MCS is 1.5 cm, ACS is 1 cm
390	400	95	5	As above, but MCS is 1 cm, ACS is 0.5 cm
400	410	97	3	As above, but MCS is 1.5 cm, ACS is 1.5 cm
410	420	85	15	As above, but MCS is 0.5 cm, ACS is 0.5 cm
420	430	97	3	As above, but MCS is 0.5 cm, ACS is 0.5 cm

**relative amount of sand is difficult to quantify*

PERCENTAGE LOG OF WATER-WELL CUTTINGS

UTAH GEOLOGICAL SURVEY

DWRi Appropriation #: 73-143 (UI7200)
Location: (C-35-11)9abb, Iron County, Utah
Driller: Grimshaw & Sons

Well Owner: Angus Water Co.

Geologist: Janae Wallace, 12/21/98

DEPTH RANGE (feet)		PERCENTAGES unconsolidated		COMMENTS
		clay/silt/ sand**	gravel*	
0	10	100	tr	Light pinkish-brown clay, silt, sand, and minor gravel; sand is fine to coarse, angular to rounded, and consists of quartz, feldspar, chert, and rock fragments; trace black carbonaceous material; calcareous
10	20	99	1	As above, but gravel is angular; MCS is 0.5 cm, ACS is 0.5 cm; trace bladed gypsum
20	30	98	2	As above, but gravel is angular to rounded and consists of sandstone and chert; MCS is 0.5 cm, ACS is 0.5 cm
30	40	15	85	Light pinkish-brown clay, silt, sand, and yellow, tan, gray, and pink gravel; sand is fine to coarse, angular to rounded, and consists of quartz, feldspar, chert, and rock fragments; gravel is angular to rounded and consists of chert, sandstone, limestone, and igneous clasts; MCS is 1.5 cm, ACS is 0.5 cm; trace black carbonaceous material and white shell fragments; calcareous
40	50	90	10	As above, but light brown; trace gypsum; no shell fragments; MCS is 1 cm, ACS is 1 cm
50	60	97	3	As above, but MCS is 1.5 cm, ACS is 1 cm
60	70	97	3	As above, but MCS is 1 cm, ACS is 1 cm
70	80	10	90	As above, but tan, pink, and gray gravel; MCS is 1 cm, ACS is 1 cm
80	90	95	5	As above, but light pinkish-brown; MCS is 2 cm, ACS is 1 cm
90	100	95	5	Light pinkish-brown clay, silt, sand, and gravel; sand is fine to coarse, angular to rounded, and consists of quartz, feldspar, chert, and rock fragments; gravel is angular to rounded and consists of chert, sandstone, limestone, and igneous clasts; MCS is 2 cm, ACS is 0.7 cm; trace black carbonaceous material; calcareous
100	110	90	10	As above, but light orangish-brown; MCS is 2 cm, ACS is 0.7 cm
110	120	10	90	As above, but light brown; no black carbonaceous material; MCS is 1 cm, ACS is 1 cm
120	130	10	90	As above, but MCS is 1 cm, ACS is 1 cm
130	140	10	90	As above, but gravel is tan, red, gray, and yellow; MCS is 1 cm, ACS is 1 cm; trace black carbonaceous material
140	150	5	95	As above, but MCS is 1 cm, ACS is 0.7 cm
150	160	40	60	As above, but light orangish-brown; MCS is 1 cm, ACS is 1 cm
160	170	90	10	As above, but MCS is 1.5 cm, ACS is 0.5 cm
170	180	50	50	As above, but MCS is 1 cm, ACS is 1 cm
180	190	50	50	As above, but MCS is 0.5 cm, ACS is 0.5 cm
190	200	90	10	As above, but MCS is 0.5 cm, ACS is 0.5 cm
200	210	90	10	As above, but MCS is 1 cm, ACS is 1 cm
210	220	98	2	As above, but MCS is 0.4 cm, ACS is 0.4 cm
220	230	15	85	As above, but MCS is 0.5 cm, ACS is 0.5 cm; no black carbonaceous material
230	240	50	50	As above, but MCS is 0.6 cm, ACS is 0.6 cm
240	250	50	50	As above, but MCS is 1 cm, ACS is 0.7 cm
250	260	98	2	Light orangish-brown clay, silt, sand, and yellow, tan, gray, and pink gravel; sand is fine to coarse, angular to rounded, and consists of quartz, feldspar, chert, and rock fragments; gravel is angular to rounded and consists of chert, sandstone, limestone, and igneous clasts; MCS is 1 cm, ACS is 0.5 cm; trace black carbonaceous material; calcareous
260	270	97	3	As above, but MCS is 1.2 cm, ACS is 0.5 cm
270	280	97	3	As above, but MCS is 1 cm, ACS is 0.3 cm
280	290	98	2	As above, but MCS is 1 cm, ACS is 0.3 cm
290	300	95	5	As above, but MCS is 0.5 cm, ACS is 0.5 cm
300	310	60	40	As above, but MCS is 1 cm, ACS is 0.7 cm; trace gypsum
310	320	95	5	As above, but MCS is 1 cm, ACS is 0.5 cm
320	330	97	3	As above, but MCS is 1.5 cm, ACS is 1 cm

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DEPTH RANGE (feet)		PERCENTAGES unconsolidated		COMMENTS
		clay/silt/ sand**	gravel*	
330	340	98	2	As above, but MCS is 0.5 cm, ACS is 0.5 cm
340	350	90	10	As above, but MCS is 1 cm, ACS is 0.5 cm
350	360	90	10	As above, but MCS is 1 cm, ACS is 0.5 cm
360	370	97	3	As above, but MCS is 0.5 cm, ACS is 0.5 cm
370	380	95	5	As above, but MCS is 0.5 cm, ACS is 0.5 cm
380	390	97	3	As above, but MCS is 0.5 cm; ACS is 0.5 cm; no black carbonaceous material; no gypsum
390	400	98	2	As above, but MCS is 0.5 cm, ACS is 0.5 cm
400	410	95	5	As above, but MCS is 0.5 cm, ACS is 0.5 cm
410	420	99	1	Light orangish-brown clay, silt, sand, and gravel; sand is fine to coarse, angular to rounded, and consists of quartz, feldspar, chert, and rock fragments; gravel is angular to rounded and consists of chert, sandstone, limestone, and igneous clasts; MCS is 0.7 cm, ACS is 0.3 cm; trace black carbonaceous material and gypsum; calcareous
420	430	15	85	As above, but MCS is 1 cm, ACS is 0.5 cm
430	440	25	75	As above, but no black carbonaceous material; MCS is 0.7 cm, ACS is 0.7 cm
440	450	95	5	As above, but no gypsum; MCS is 0.7 cm, ACS is 0.7 cm
450	460	97	3	As above, but MCS is 0.5 cm, ACS is 0.5 cm

**relative amount of sand is difficult to quantify*

**estimated clast size may not reflect actual size encountered by the driller*

PERCENTAGE LOG OF WATER-WELL CUTTINGS

UTAH GEOLOGICAL SURVEY

DWRi Appropriation #: 99-001-M
Location: (C-35-11)25bcd, Iron County, Utah
Driller: U.S.G.S.

Well Owner: U.S.G.S.

Geologist: Janae Wallace, 7/219/99

DEPTH RANGE (feet)		PERCENTAGES unconsolidated		COMMENTS
		clay/silt/ sand	gravel*	
0	10	15	85	Pink, tan, gray, brown, yellow, and red gravel with pinkish-orange sand; sand is angular to subrounded, medium to coarse, and consists of quartz, feldspar, lithic fragments, and mafic minerals; gravel is angular to subrounded and consists of volcanic, limestone, sandstone, and chert clasts; MCS is 1.5 cm, ACS is 0.5 cm; calcareous
10	20	25	75	As above, but silt and sand; sand is fine to coarse; MCS is 4 cm, ACS is 1 cm
20	30	5	95	As above, but medium to coarse sand; MCS is 2 cm, ACS is 1 cm
30	40	5	95	As above, but MCS is 3 cm, ACS is 0.5 cm
40	50	2	98	As above, but MCS is 4 cm, ACS is 1 cm; moderately calcareous
50	60	tr	100	As above, but MCS is 3 cm, ACS is 1.5 cm
60	70	tr	100	As above, but MCS is 2 cm, ACS is 1 cm
70	80	tr	100	As above, but MCS is 2.5 cm, ACS is 1 cm
80	90	tr	100	As above, but MCS is 2 cm, ACS is 1 cm
90	100	2	98	As above, but MCS is 2 cm, ACS is 0.5 cm
100	110	tr	100	As above, but MCS is 2.5 cm, ACS is 1 cm
110	120	tr	100	As above, but MCS is 3.5 cm, ACS is 1 cm
120	130	1	99	Pink, tan, gray, brown, yellow, and red gravel with pinkish-orange sand; sand is angular to subrounded, medium to coarse, and consists of quartz, feldspar, lithic fragments, and mafic minerals; gravel is angular to subrounded and consists of volcanic, limestone, sandstone, and chert clasts; MCS is 2.5 cm, ACS is 1 cm; calcareous
130	140	1	99	As above, but MCS is 3 cm, ACS is 1 cm
140	150	2	98	As above, but sand is fine to coarse; MCS is 1 cm, ACS is 0.5 cm
150	160	2	98	As above, but MCS is 1.5 cm, ACS is 0.5 cm
160	170	5	95	As above, but MCS is 1 cm, ACS is 0.5 cm
170	180	5	95	As above, but MCS is 2.5 cm, ACS is 1 cm
180	190	10	90	As above, but MCS is 3 cm, ACS is 1 cm; gravel is angular
190	200	5	95	As above, but MCS is 2 cm, ACS is 0.5 cm
200	210	5	95	As above, but MCS is 1 cm, ACS is 0.5 cm
210	220	5	95	As above, but pinkish-orange silt and sand; MCS is 3.5 cm, ACS is 0.5 cm
220	230	3	97	As above, but reddish-orange silt and sand; MCS is 2 cm, ACS is 1 cm
230	240	5	95	As above, but MCS is 2 cm, ACS is 0.5 cm
240	250	5	95	As above, but MCS is 1 cm, ACS is 0.7 cm
250	260	2	98	As above, but MCS is 2.5 cm, ACS is 1 cm
260	270	5	95	Pink, tan, gray, and green gravel with tan silt and sand; sand is angular to subrounded, very fine to coarse, and consists of quartz, feldspar, lithic fragments, and mafic minerals; gravel is angular and consists of volcanic, sandstone, limestone, and chert clasts; MCS is 2 cm, ACS is 1 cm; calcareous
270	280	10	90	As above, but orange silt and sand; MCS is 2 cm, ACS is 0.5 cm
280	290	2	98	Grayish-pink and yellow angular gravel with minor sand; this interval dominantly consists of broken up pink microcrystalline tuff and likely represents a boulder encountered by the driller; silt/sand content is likely the disaggregated volcanic clast; moderately calcareous
290	300	2	98	Pink, gray, brown, and yellow gravel with pinkish-tan silt and sand; sand is angular to sub rounded, very fine to coarse, and consists of quartz, feldspar, lithic fragments, and mafic minerals; gravel is angular, consists of volcanic, sandstone, limestone, and chert clasts; MCS is 1 cm, ACS is 1 cm; moderately calcareous

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DEPTH RANGE (feet)		PERCENTAGES unconsolidated		COMMENTS
		clay/silt/ sand**	gravel*	
300	310	5	95	As above, but MCS is 2 cm, ACS is 0.5 cm
310	320	5	95	As above, but MCS is 1 cm, ACS 0.5 cm

**estimated clast size may not reflect actual size encountered by the driller; angularity of the grains may be the result of action of the drill on the sedimentary materials.*

PERCENTAGE LOG OF WATER-WELL CUTTINGS

UTAH GEOLOGICAL SURVEY

DWRi Appropriation #: 99-73-003-P Well Owner: Iron Co. School District
Location: (C-35-11)35bdb, Iron County, Utah
Driler: Geo Energy Systems Geologist: Janae Wallace, 7/14/99

DEPTH RANGE (feet)		PERCENTAGES unconsolidated			COMMENTS
		clay/	silt/sand	gravel*	
0	10	0	20	80	Pink, tan, gray, green, brown, and red gravel with pinkish-orange silt and sand; sand is angular to subrounded, very fine to coarse, and consists of quartz, feldspar, and mafic minerals; gravel is angular to subrounded and consists of volcanic, lime stone, sandstone, and chert clasts; MCS is 3 cm, ACS is 1 cm; calcareous
10	20	0	2	98	As above, but MCS is 2 cm, ACS is 1 cm
20	30	tr	5	95	As above, but trace clay; MCS is 4 cm, ACS is 1 cm
30	40	tr	3	97	As above, but MCS is 2 cm, ACS is 1 cm
40	50	2	5	93	As above, but MCS is 4 cm, ACS is 2 cm
50	60	5	15	80	As above, but MCS is 2 cm, ACS is 1 cm
60	70	2	5	93	As above, but MCS is 2 cm, ACS is 1 cm
70	80	1	4	95	As above, but MCS is 2.5 cm, ACS is 1 cm
80	90	tr	5	95	As above, but MCS is 2 cm, ACS is 0.5 cm
90	100	0	2	98	As above, but no clay; MCS is 3 cm, ACS is 1 cm
100	110	0	1	99	As above, but MCS is 2 cm, ACS is 1 cm
110	120	0	3	97	As above, but MCS is 2 cm, ACS is 0.5 cm
120	130	0	3	97	As above, but tan silt and sand; MCS is 2.5 cm, ACS is 1 cm
130	140	0	tr	100	Tan, red, pink, gray, and green gravel with tan silt and sand; sand is angular to sub rounded, very fine to coarse, and consists of quartz, feldspar, and mafic minerals; gravel is angular to subrounded and consists of sandstone, limestone, volcanic, and chert clasts; MCS is 2 cm, ACS is 0.5 cm; calcareous
140	150	tr	2	98	As above, but trace clay; MCS is 1.5 cm, ACS is 1 cm
150	160	0	2	98	As above, but no clay; MCS is 3 cm, ACS is 1 cm
160	170	0	1	99	As above, but tan, yellow, and gray; MCS is 2 cm, ACS is 1 cm
170	180	0	3	97	As above, but MCS is 2.5 cm, ACS is 1 cm
180	190	0	2	98	As above, but MCS is 3 cm, ACS is 1 cm
190	200	0	0	100	As above, but no silt/sand; gray, pink, and tan gravel; MCS is 2.5 cm, ACS is 1 cm
200	210	0	tr	100	As above, but trace silt/sand; MCS is 1.5 cm, ACS is 1 cm
210	220	0	5	95	As above, but MCS is 3.5 cm, ACS is 0.5 cm
220	230	0	0	100	As above, but no silt/sand; MCS is 2 cm, ACS is 1 cm
230	240	0	tr	100	As above, but trace silt/sand; MCS is 1.5 cm, ACS is 0.5 cm
240	250	tr	50	50	Pink, tan, gray, green, brown, and red gravel with pinkish-orange silt and sand and trace clay; sand is angular to subrounded, very fine to coarse, and consists of quartz, feldspar, and mafic minerals; gravel is angular to subrounded and consists of sandstone, limestone, volcanic, and chert clasts; MCS is 1 cm, ACS is 0.5 cm; calcareous
250	260	tr	50	50	As above, but MCS is 1 cm, ACS is 0.5 cm
260	270	tr	25	75	Pink, tan, gray, and green gravel with pinkish-orange silt and sand and minor clay; sand is angular to subrounded, very fine to coarse, and consists of quartz, feldspar, and mafic minerals; gravel is angular to subrounded and consists of sandstone, limestone, volcanic, and chert clasts; MCS is 0.7 cm, ACS is 0.4 cm; calcareous
270	280	2	8	90	As above, but MCS is 1 cm, ACS is 0.4 cm
280	290	2	18	80	As above, but MCS is 0.7 cm, ACS is 0.4 cm
290	300	2	18	80	As above, but MCS is 1 cm, ACS 0.5 cm

**estimated clast size may not reflect actual size encountered by the driller; angularity of the grains may be the result of action of the drill on the sedimentary materials.*

APPENDIX C

Water-Quality Data for 1979-81 and 1999

Table A-3
Water quality data from 1979 to 1989 and 1999

well #	location	depth (feet)	perforated interval (feet)	nitrate mg/L-1999	nitrate mg/L-1979-81
1	(C-35-11)34dbb	300	0-152	—	4.16
2	(C-35-11)26ccb	200	160-200	—	5.04
3	(C-35-11)35bdd	401	361-401	—	36.73
4	(C-36-11)11bdb	670	221-623	—	9.4
5	(C-35-11)27bcb	198	mp66-190	5.7	5.32
6	(C-35-11)24ccd	182	167-182	10.8	28.15
7	(C-35-10)18acb	400	140-400	—	1.35
8	(C-35-11)12ddc	300	260-300	23.1	3.04
9	(C-35-11)12ccc	228	—	—	5.21
10	(C-35-11)11bab	400	240-400	—	0.37
11	(C-35-11)11dcc	301	—	2.6	2.27
12	(C-35-11)13cbc	516	445-510	—	15.08
13	(C-35-11)23abb	96	—	22.4	20.2
14	(C-35-11)23acc	385	200-353	—	34.89
15	(C-35-11)22add	500	170-500	—	13.25
16	(C-35-11)9abc	595	200-595	—	0.67
17	(C-34-11)33dac	289	mp97-276	—	0.46
18	(C-35-11)16dba	335	255-335	—	5.15
19	(C-35-11)16ccc	240	200-240	—	2.67
20	(C-35-11)8ddc	300	205-300	—	0.81
21	(C-35-11)6aca	255	215-255	—	0.29
22	(C-35-11)19bda	800	510-765	—	0.23
23	(C-35-11)21cdd	252	mp100-252	—	3.21
24	(C-35-11)32dba	—	—	—	5.55
25	(C-36-11)5dca	425	—	—	8.3
26	(C-36-11)7aaa	300	100-300	—	6.54
27	(C-35-12)36dab	415	182-392	—	0.19
28	(C-35-11)15acc	700	150-700	—	2.65
29	(C-35-11)29abd	290	230-290	—	3.56
30	(C-35-11)23acd	500	—	—	38.94
31	(C-35-11)32cdd	—	—	—	2.91
36	(C-35-11)13ddb	263	—	—	13.4
37	(C-35-11)24aab	800	—	—	4.4
38	(C-35-11)13dca	263	150-263	11	17.89
39	(C-35-11)24bdd	141	mp115-141	—	12.2
40	(C-35-11)24bda	400	360-400	—	0.18
42	(C-35-10)18bcb	800	115-700	—	3.74
43	(C-35-10)18bbc	—	—	—	8.53
47	(C-35-11)14ddd	—	—	9.9	0.06
48	(C-35-11)14ddc	330	240-330	—	7.58
49	(C-35-11)23abd	—	—	—	4.3
50	(C-35-11)23ada	—	—	—	5.3
51	(C-35-11)26dca	—	—	—	10.65
52	(C-35-11)26acd	700	140-400	—	10.42
53	(C-35-11)26bca	300	260-300	2.2	5.92

(Table A-3 continued)

well #	location	depth (feet)	perforated interval (feet)	nitrate mg/L-1999	nitrate mg/L-1979-81
54	(C-35-11)27bbb	—	—	—	5.64
55	(C-35-11)27bca	—	—	—	5.29
56	(C-35-11)27bbd	—	—	—	4.13
57	(C-35-11)27bac	—	—	—	4.11
58	(C-35-11)27bdb	—	—	—	3.72
59	(C-35-11)27abb	—	—	—	2.57
61	(C-35-11)27acb	—	—	—	4.59
62	(C-35-11)27dbb	228	100-190	—	4.7
63	(C-35-11)27cda	—	—	—	6.57
64	(C-35-11)34abd	—	—	—	2.7
65	(C-35-11)3abd	—	—	—	0.41
66	(C-35-11)34dcc	187	165-187	—	0.69
67	(C-35-11)35bbb	—	—	—	2.17
68	(C-35-11)26cbc	—	—	—	4.7
69	(C-35-11)26cba	263	120-265	—	2.7
70	(C-35-11)37acd-1	385	200-353	1.6	2.07
71	(C-35-11)27acd-2	—	—	—	4.78
72	(C-35-11)27aca	300	260-300	—	7.64
73	(C-35-11)27abb	—	—	9.9	23.96
74	(C-35-11)22dcd	—	—	7	57.4
75	(C-35-11)22ddc	—	—	—	21.2
76	(C-35-11)22dba	301	231-301	—	7.97
77	(C-35-11)22dbd	300	140-280	—	5.18
78	(C-35-11)22adc	116	101-116	4.1	3.62
79	(C-35-11)22dbb	290	mp125-268	—	4.68
8	(C-35-11)22dad	350	120-350	—	13.21
81	(C-35-11)23bcc	184	184	—	4.18
82	(C-35-11)23cba	315	304-314	1	37.32
83	(C-35-11)23bdd	161	mp95-143	—	14.21
84	(C-35-11)22acb	238	202-280	7.4	8.36
85	(C-35-11)15aab	—	—	—	2.92
86	(C-35-11)14bac	—	—	—	2.19
87	(C-35-11)11cdc	450	200-450	22	11.26
88	(C-35-11)11ccd	330	290-330	—	4.12
89	(C-35-11)11ccc	300	mp216-300	6.3	6.3
90	(C-35-11)10dcc	305	mp267-304	3	2.4
91	(C-35-11)10dcd	—	—	—	2.96
92	(C-35-11)10dcd	700	200-700	2.3	4.54
93	(C-35-11)15aba	362	—	9	8.91
94	(C-35-11)10ccd	—	—	—	3.83
95	(C-35-11)10cdd	500	220-500	—	0.68
96	(C-35-11)15baa	—	—-	—	2.63
97	(C-35-11)10ccd-1	315	275-315	—	0.57
98	(C-35-11)10ccd-2	450	100-450	—	0.66
99	(C-35-11)10dcc	—	—	—	3.57
100	(C-35-11)26bbb	—	—	3.1	11.4
101	(C-35-11)35cad	238	200-238	—	7.08
102	(C-35-11)25bcd	320	—	—	7.00

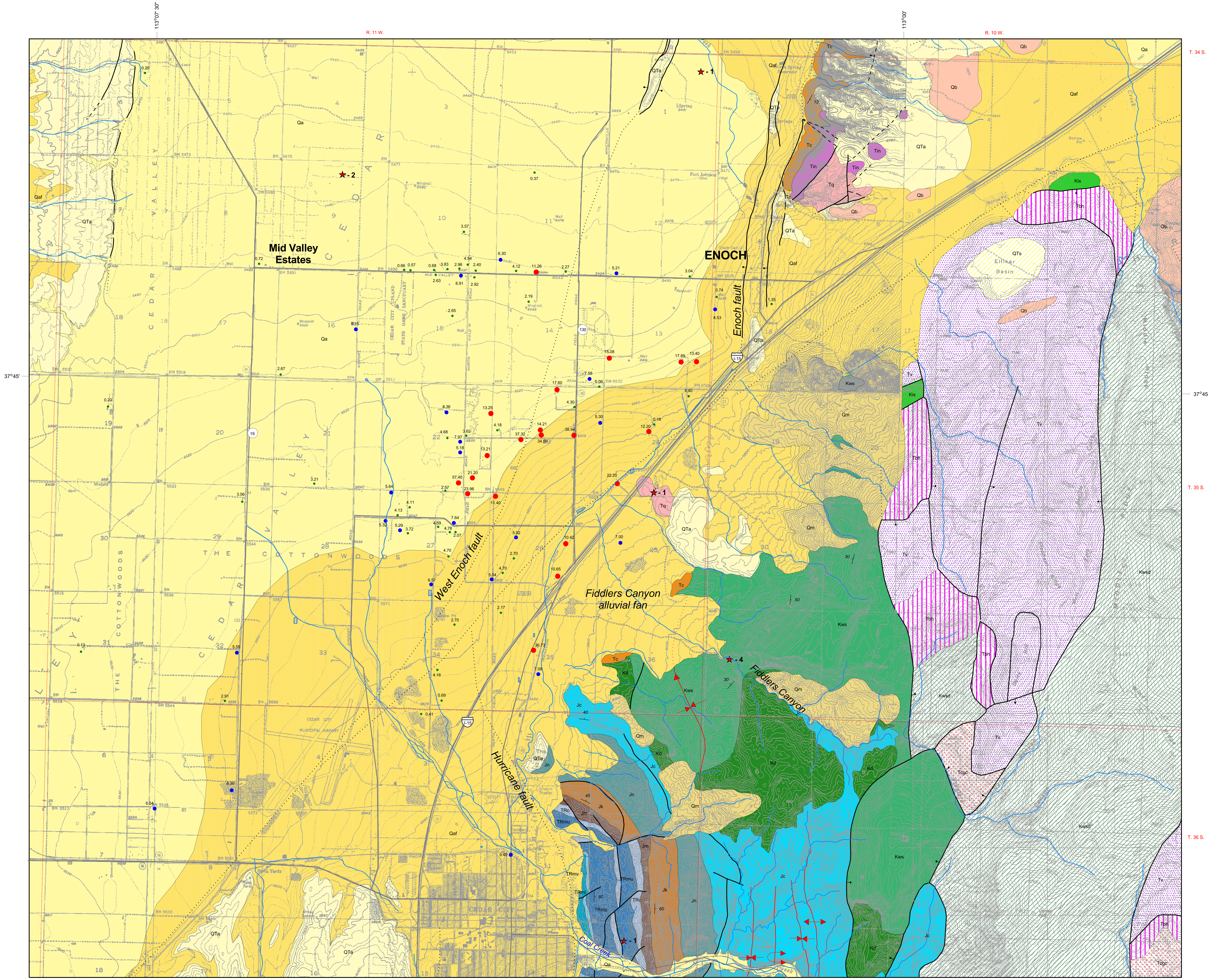
**mp = multiple perforations*

Plate 1

Compiled geologic map of the Enoch study area, Cedar Valley, Iron County, Utah

See figure 4 for sources of compilation

Geology compiled by Hurlow (in prep.)



1:48,000

0.5 0 0.5 1 Miles

0.5 0 0.5 1 Kilometers

N

EXPLANATION

Contact

Faults

Normal fault inferred where dashed, concealed where dotted, ball and bar on downthrown side

Folds

Anticline

Syncline, showing plunge direction dotted where concealed

Overturned anticline

Strike and dip of bedding

45 Inclined

Wells

★ - 1 Natural nitrogen sampling site- number refers to the number of samples obtained

Nitrate concentrations (measured value labeled).

- 0-4.99 mg/L
- 5.0-9.99 mg/L
- 10+ mg/L

Units

Quaternary

Qm Mass-movement deposits- Landslide and slump deposits, including some talus and colluvium.

Qa Alluvium- Brown to tan gravel and sand and tan to red silt and clay, deposited in alluvial-fan, stream, and debris-flow environments.

Qaf Alluvial- fan deposits- Poorly sorted, poorly to moderately stratified gravel, sand, silt, and clay; clasts are pebble to boulder size; deposited along valley margins where ephemeral and perennial streams enter the valley; gradational with Quaternary alluvium.

Qb Basalt- Dark gray and black, dense, vesicular flows with olivine or olivine and plagioclase phenocrysts; local deposits of black and red, poorly consolidated scoria. Includes local cinder and ash deposits on the Markagunt Plateau east and southeast of Cedar City.

Quaternary-Tertiary

QTa Alluvium- Brown to tan gravel and sand and tan to red-tan silt and clay, deposited in alluvial-fan, stream, and debris-flow environments. Typical exposures include beds of massive, unsorted pebble to boulder gravel, silty sand, and clay in variable proportions.

QTs Poorly consolidated sediments (Pleistocene, Pliocene, and Miocene)- Mostly poorly consolidated light gray or tan sandy fine-pebble to boulder conglomerate or less commonly, coarse-grained colluvium derived from such deposits.

Tertiary

Tv Tertiary volcanic rocks, undivided.

Tq Quichapa Group- Undifferentiated formations of brown, salmon, and tan, moderately welded, crystal-poor ash-flow tuff with minor to abundant volcanic fragments; brownish-red, densely welded, crystal-poor ash-flow tuff; and light tan, pink, grayish-orange, and light red-brown, moderately welded, crystal-rich, trachytic-andesitic to andesitic ash-flow tuff.

Tin Isom Formation and Needles Range Group- Needles Range Group consists of grayish-orange-pink to light brownish-gray, moderately welded, dacitic ash-flow tuffs. Isom Formation consists of two resistant, densely welded, trachytic ash-flow tuff units which consist of chocolate-brown, medium brown, tan, medium gray, or brownish-purple, crystal-poor ash-flow tuff, and medium red to tan, crystal-poor ash-flow tuff containing abundant pin-size vesicles.

Tbh Brian Head Formation- Interbedded sandstone, shale, and volcanic tuff; sandstone is medium gray to greenish-gray, medium- to fine- grained, tuffaceous sandstone; mudstone and shale are pale olive-gray to red-brown, with moderately to poorly defined lamination; tuff is moderately indurated with orange-pink fine groundmass.

Tc Claron Formation- Pale red to white, thin- to thick-bedded sandstone,shale, and limestone with some pebble conglomerate; the upper part of the formation includes volcanic detritus.

Tcgc Claron and Grand Castle Formations, undivided- Claron Formation is described above; Grand Castle Formation is interbedded sandstone and conglomerate; conglomerate is matrix-supported and cross-bedded with rounded to subrounded, pebble- to boulder- size clasts; sandstone is cross-bedded to massive.

Cretaceous

Kis Iron Springs Formation- Yellowish-gray, grayish-yellow, medium yellow, and dark yellowish-orange, fine- to medium-grained, thin-bedded to massive sandstone. The lower part of the unit contains some carbonaceous shale and coal with some thin conglomerate beds of maroon shale at the base of the formation.

Kws Wahweap Sandstone and Straight Cliffs Formations- Gray, tan, and yellow fine-grained sandstone and siltstone containing some coal and organic-rich fossiliferous seams.

Kd Dakota Formation- Light to dark gray shale with pale yellowish-orange, fine- to medium-grained sandstone.

Kwsd Wahweap, Straight Cliffs, and Dakota Formations, undivided

Jurassic

Jc Carmel Formation- Locally fossiliferous, light gray, thin bedded, shaly limestone; red-brown sandstone, siltstone, and mudstone with intercalated gypsum; massive gypsum with thin-bedded limestone overlain by banded light gray and red-brown sandstone and mudstone.

Jn Navajo Sandstone- Moderate reddish-orange, fine- to medium-grained sandstone with prominent large-scale cross-bedding with minor interdunal limestone deposits.

Jk Kayenta Formation- Basal reddish-brown mudstone and silty mudstone and light gray, light brown, reddish-brown, and reddish-orange siltstone overlain by upper reddish-brown mudstone and light gray to reddish-orange siltstone.

Jm Moenave Formation- Lower red-brown siltstone and mudstone overlain by reddish- to purplish-brown, fine- to medium-grained, massive sandstone with cross-bedding.

Triassic

TRc Chinle Formation- Basal conglomerate overlain by reddish-brown and grayish-red mudstone and siltstone.

Moenkopi Formation-

TRmu Upper red member- Red-brown and light brown siltstone and mudstone intercalated with gypsum. Includes TRmc and TRmu.

TRmv Virgin Limestone Member- Fine-grained limestone and silty shale with basal fossiliferous unit.

TRml Lower red member- Red-brown siltstone and mudstone with intercalated gypsum.

Projection: UTM Zone 12
Units: Meters
Datum 1927 North America
Spheroid: Clarke 1866

Base maps from U.S. Geological Survey
Three Peaks 7.5 minute quadrangle, contour interval 20 feet
Enoch 7.5 minute quadrangle, contour interval 10 feet
Summit 7.5 minute quadrangle, contour interval 40 feet
Cedar City NW 7.5 minute quadrangle, contour interval 20 feet
Cedar City 7.5 minute quadrangle, contour interval 40 feet
Flanigan Arch 7.5 minute quadrangle, contour interval 40 feet