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**REVIEW AND RECONNAISSANCE OF THE
HYDROGEOLOGY OF TERTIARY
SEDIMENTARY ROCKS IN THE VICINITY OF
FRENCHMAN FLAT, NEVADA TEST SITE**

September 1997

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VICINITY OF FRENCHMAN FLAT, NEVADA TEST SITE**

by

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September 1997

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List of Acronyms and Abbreviations

AA	Alluvial Aquifer
CAU	Corrective Action Unit
FFACO	Federal Facility Agreement and Consent Order
LCA	Lower Carbonate Aquifer
LCCU	Lower Clastic Confining Unit
NTS	Nevada Test Site
SWNVF	southwestern Nevada volcanic field
TCU	Tuff Confining Unit
TMA	Timber Mountain Aquifer
UGTA	Underground Test Area (subproject)
VCU	Volcaniclastic Confining Unit
WVCU	Wahmonie Volcanic Confining Unit

1.0 INTRODUCTION

Work is currently underway within the Underground Test Area (UGTA) subproject of the U.S. Department of Energy/Nevada Operations Office Environmental Restoration Program to develop corrective action plans in support of the overall corrective action strategy for the Nevada Test Site (NTS) as established in the *Federal Facility Agreement and Consent Order* (FFACO, 1996). A closure plan is currently being developed for Frenchman Flat, which has been identified in the FFACO as a Corrective Action Unit (CAU). Part of this effort requires that hydrogeologic data be compiled for inclusion in a CAU-specific hydrologic flow and transport model that will be used to predict contaminant boundaries. Hydrogeologic maps and cross sections are currently being prepared for use in the model to define the nature and extent of aquifers and confining units that might influence the flow of contaminated groundwater from underground nuclear tests conducted in Frenchman Flat.

During this effort, it has been found that older Tertiary-age sediments might be hydrogeologically important in the Frenchman Flat model area. Although the character and extent of these units are poorly known, there is reason to believe that in some parts of Frenchman Flat they may lie between the regional Lower Carbonate Aquifer (LCA) and the younger Tertiary saturated alluvium and volcanic units in which several underground nuclear tests were conducted. It was not possible to quickly determine their extent, or ascertain whether or not these units might act as confining units or aquifers. The work described in this report was done to gain a better understanding of the hydrogeology of these rocks.

1.1 Objectives

The main objective of this study was to develop a simplified conceptual hydrogeologic model of the Tertiary sedimentary rocks in the vicinity of Frenchman Flat so that these rocks could be accurately depicted on Frenchman Flat CAU cross sections and unit-extent maps. To develop a realistic conceptual model, the following two critical questions regarding the hydrogeology of these rocks had to be answered: (1) What are the hydraulic characteristics of these rocks? (i.e., are they aquifers or confining units?), and (2) What is the thickness and extent of these rocks beneath Frenchman Flat?

A secondary objective of the study was to document the assumptions, generalizations, and constraints on the hydrogeology of the Tertiary sedimentary rocks as applied to the construction of the cross sections and unit-extent maps. Finally, this report is intended to

serve as a resource base on the current state of knowledge on the geology and hydrogeology of the Tertiary sedimentary rocks in the southern portion of the NTS.

1.2 Methods of Study

The study began with the gathering and review of published geologic and hydrogeologic information on the Tertiary sedimentary rocks. This information included geologic maps, drill hole reports, and various geologic and hydrogeologic reports (see Section 6.0, References). Because much of the information and work on these rocks has not yet been published, personal communication with geologists of the United States Geological Survey and the Los Alamos National Laboratory was a critical part of the study.

The authors conducted a field reconnaissance of the Tertiary sedimentary rocks to gain an understanding of the hydraulic character of the rocks and to determine the stratigraphic and hydrogeologic relationships between the older Tertiary rocks north of Frenchman Flat and those exposed south and southwest of Frenchman Flat. The reconnaissance involved visits to outcrop exposures where photographs and field sketches were made and samples collected (Appendix A). Later the samples were examined and described using a microscope (Appendix B). During both outcrop and sample examination, particular attention was given to those properties and characteristics that could influence the ability of rocks to transmit groundwater. Samples collected during the reconnaissance are available from the United States Geological Survey Core Library in Mercury, Nevada. Photographs and field sketches are on file at the Bechtel Nevada Geology/Hydrology office in Mercury, Nevada. In addition, drill cuttings, core, geophysical logs, and hydrologic data from existing drill holes that encountered the rocks of interest were also examined.

1.3 Hydrogeologic Setting

A brief synopsis of the geology and hydrogeology of Frenchman Flat is presented in this section. More detail can be found in the references listed in Section 6.0 of this report.

1.3.1 Physiography

Frenchman Flat is a closed intermontane basin located in the southeastern portion of the NTS. It is bounded on the north by Massachusetts Mountain and the Halfpint Range, on the east by the Buried Hills, on the south by the Spotted Range, and on the west by the Wahmonie volcanic center (Figure 1-1). The sparsely vegetated valley floor slopes gently toward a central playa lakebed. Ground level elevations range from 938 meters (m) (3,078 feet [ft]) above sea level at the playa, to over 1,219 m (4,000 ft) in the nearby surrounding mountains.

Figure 1-1. Generalized geologic map of the Frenchman Flat vicinity.

1.3.2 Geology

The generalized stratigraphic section for the Frenchman Flat area consists of (from oldest to youngest) Proterozoic and Paleozoic clastic and carbonate rocks, Tertiary sedimentary rocks, Tertiary volcanic rocks, and Quaternary and Tertiary alluvium. In the northern portion of Frenchman Flat volcanic rocks, erupted mostly from calderas located to the northwest of Frenchman Flat, unconformably overlie Paleozoic carbonate and clastic rocks. To the south, most of these volcanic units, including the Ammonia Tanks Tuff, Rainier Mesa Tuff, Topopah Spring Formation, and Crater Flat Group, either thin considerably or pinch out altogether. Tuffs, lavas, and debris flows from the Wahmonie volcanic center dominate the volcanic section in the western portion of the valley. To the south and southeast, most of the volcanic units are absent and older Tertiary (Miocene and Oligocene) sedimentary rocks, which unconformably overlie the Paleozoic rocks in the southern portion of Frenchman Flat, dominate the Tertiary section. In most of the Frenchman Flat area, the older rocks are covered by alluvium. Alluvium thicknesses range from a thin veneer along the valley edges to perhaps as much as 1,000 m (3,300 ft) in north-central Frenchman Flat.

The structural geology of the Frenchman Flat region is complex. During the late Mesozoic, the region was subjected to compressional deformation resulting in folding, thrusting, uplift, and erosion of the pre-Tertiary rocks. In more recent times (Miocene to Quaternary), the region has undergone extensional deformation during which the present basin-and-range topography was developed and the Frenchman Flat basin was formed. Extensional deformation produced east-northeast-striking strike-slip faults such as the Rock Valley fault, as well as numerous generally north-striking normal faults that displace the Tertiary and pre-Tertiary rocks.

1.3.3 Hydrology

The rocks beneath Frenchman Flat can be divided into seven hydrostratigraphic units based on their hydrologic properties and stratigraphic position (modified from Winograd and Thordarson, 1975). In ascending order, these units are: the Lower Clastic Confining Unit (LCCU), LCA (the regional aquifer), Volcaniclastic Confining Unit (VCU [comprising the Tertiary sedimentary rocks discussed in this report]), Wahmonie Volcanic Confining Unit (WVCU), Tuff Confining Unit (TCU), Timber Mountain Aquifer (TMA), and the Alluvial Aquifer (AA). The LCCU and LCA are regional units and therefore inferred to be present everywhere beneath Frenchman Flat. The distribution of the younger hydrostratigraphic units is governed by local depositional patterns, structure, and subsequent erosion.

The static water level in Frenchman Flat is relatively flat, with an elevation of about 731 m (2,400 ft) above sea level (Winograd and Thordarson, 1975). However, depth to water below ground level varies with topography, ranging from 209 m (687 ft) in the central portion of Frenchman Flat to about 393 m (1,290 ft) at Well UE-11b in the north. The static water level is generally located within the VCU, TCU, or the WVCU but, in the deeper portions of Frenchman Flat, the TMA and lower portion of the AA are also saturated. Perched and semiperched water is recognized within altered units (primarily the WVCU) in several drill holes along the western margin of the valley. Regional groundwater flow is generally to the south-southwest (Laczniak *et al.*, 1996).

2.0 HYDROGEOLOGY OF THE TERTIARY SEDIMENTARY ROCKS

2.1 Tertiary Sedimentary Rocks South and Southwest of Frenchman Flat

Tertiary sedimentary rocks exposed south and southwest of Frenchman Flat have been mapped as two formations. An older Oligocene-age unit was designated the Horse Spring Formation by Hinrichs (1968) and Barnes *et al.* (1982). However, these rocks are older than the Horse Spring Formation mapped in the Lake Mead region by Bohannon (1984). Wahl *et al.* (1996) included Oligocene-age sedimentary rocks in the Frenchman Flat area within an Oligocene- to Early Miocene-age compilation unit they called "prevolcanic sedimentary rocks." This compilation unit included Tertiary sedimentary rocks of the NTS area that appear to predate southwestern Nevada volcanic field (SWNVF) activity (Wahl *et al.*, 1996). Yount (personal communication, 1996) designated the Oligocene-age sedimentary rocks exposed in the southern portion of the NTS, particularly in the vicinity of Winapi Wash, as the Rocks of Winapi Wash. Throughout the remainder of this report, Oligocene-age sedimentary rocks that occur south and southwest of Frenchman Flat will be referred to as Rocks of Winapi Wash after Yount (personal communication, 1996). This is based on the following reasons:

- The rocks do not correlate with the Horse Spring Formation of Bohannon (1984).
- They form a distinct stratigraphic unit within the study area.
- Correlation to rocks outside of the study area is uncertain, and beyond the scope of this study.

Overlying the Oligocene-age sedimentary rocks south and southwest of Frenchman Flat is a diverse assemblage of interbedded Miocene-age volcanic and sedimentary rocks that were designated Rocks of Pavits Spring by Hinrichs (1968) and Barnes *et al.* (1982). Wahl *et al.* (1996) included the Rocks of Pavits Spring within a Miocene-age compilation unit called "older synvolcanic sedimentary rocks." This compilation unit encompassed Miocene-age sedimentary deposits of the NTS area that are older than the Timber Mountain Group and which were deposited at least partly contemporaneous with SWNVF activity (Wahl *et al.*, 1996). Yount (personal communication, 1996) used the same designation for these rocks as Hinrichs (1968) and Barnes *et al.* (1982), referring to them as the Rocks of Pavits Spring. This report will also refer to the Miocene-age sedimentary rocks that occur south and southwest of Frenchman Flat as Rocks of Pavits Spring after Hinrichs (1968) and Barnes *et al.* (1982). This is because these rocks form a distinct

stratigraphic unit within the study area, and because correlation to rocks outside the study area is uncertain and beyond the scope of this study. Figure 2-1 depicts the evolution of stratigraphic nomenclature for the Tertiary sedimentary rocks in the vicinity of Frenchman Flat.

2.1.1 Rocks of Winapi Wash

2.1.1.1 Extent and Thickness

The Rocks of Winapi Wash are exposed along the flanks of highlands that bound Frenchman Flat to the south and southwest (*Figure 1-1*). These Tertiary sedimentary rocks unconformably overlie Cambrian to Ordovician-age sedimentary rocks (Hinrichs, 1968; and Barnes *et al.*, 1982). It is likely that the Rocks of Winapi Wash are present beneath the southern portion of Frenchman Flat, and may extend as far north as the central portion of the basin. The formation is probably not present beneath the northern portion of Frenchman Flat.

The upper contact of the formation is probably an unconformity, which may account for the observed variability in the thickness of the formation. The maximum thickness appears to be less than 305 m (1,000 ft) in the area (Barnes *et al.*, 1982; Hinrichs, 1968). However, numerous faults in the area and the lateral discontinuous nature of individual units within the formation make estimates of formation thickness very uncertain. Beneath the central portion of Frenchman Flat, gravity data (Wahl, 1995) and numerous cross sections constructed through the area for the Frenchman Flat CAU generally constrain the thickness to less than 100 m (328 ft) (Drellack and Prothro, 1997).

2.1.1.2 Age and Correlation

The Rocks of Winapi Wash have been determined to be Oligocene in age (Yount, personal communication, 1996), based partly on an age date of 30.2 million years obtained from an interbedded tuff (Marvin *et al.*, 1970). The rocks were formerly mapped as the Horse Spring Formation (Hinrichs, 1968; and Barnes *et al.*, 1982), but are older than the Miocene-age Horse Spring Formation in the Lake Mead region (Bohannon, 1984). The occurrence of Oligocene-age sedimentary rocks appears to be limited in southern Nevada (Yount, personal communication, 1996). However, the Rocks of Winapi Wash may correlate to possible Oligocene-age sedimentary rocks west of Mount Helen (Wahl *et al.*, 1996), the Titus Canyon Formation exposed along the flank of the Funeral Mountains (Yount, personal communication, 1996), and/or the Sheep Pass Formation in the Egan Range (Tschanz and Pampeyan, 1970).

Figure 2-1. Evolution of stratigraphic nomenclature for Tertiary sedimentary rocks in the of Frenchman Flat (also includes Lake Mead region).

2.1.1.3 Lithology and Hydraulic Character

The Rocks of Winapi Wash consist mainly of interbedded sedimentary rocks and minor intercalated tuff. In the vicinity of Hampel Wash, southwest of Frenchman Flat, Hinrichs (1968) described the Horse Spring Formation (Rocks of Winapi Wash in this report) as consisting of siltstone, limestone, claystone, sandstone, tuff, and conglomerate. Barnes *et al.* (1982) divided the same formation in the southern portion of Frenchman Flat into three units: (1) a unit containing mostly thin- and thick-bedded argillaceous and silty limestone, (2) a unit containing lenses of conglomerate consisting of pre-Tertiary clasts in a tuffaceous sandstone matrix (lack of volcanic clasts in the conglomerate is diagnostic [Wahl *et al.*, 1996]), and (3) a relatively thin unit of bedded tuff. The formation is bedded and many of the units appear to be laterally discontinuous.

The authors are unaware of any of quantitative hydraulic tests performed on these rocks, but some general hydraulic characteristics can be inferred from lithologic and stratigraphic information. The limestones are fractured and therefore probably capable of transmitting groundwater. However, individual limestone beds are relatively thin (less than 1 m [3 ft] thick) and probably of limited lateral extent. The coarser clastic rocks, such as sandstone and conglomerate, are probably also capable of transmitting water but, like the limestone, many of the individual units appear to be of limited vertical and lateral extent.

The finer clastic rocks (such as the claystones) are probably not capable of transmitting significant amounts of groundwater. Because these units are interbedded throughout the formation, they probably reduce the ability of the formation as a whole to transmit groundwater, particularly in a vertical direction. The few volcanic units present within the formation are likely to be zeolitized or argillized, particularly below the water table. Because zeolitization and argillation usually reduce the permeability of rocks, the presence of these volcanic intervals would also reduce the ability of the formation as a whole to transmit groundwater.

In summary, the abundance of fractured limestone and coarse clastic rocks within the formation probably impart some degree of aquifer properties to the formation as a whole. However, the limited lateral and vertical extent of these units and the presence of interbedded confining units, such as zeolitized tuff and claystone, probably reduces the ability to transmit water considerably, particularly in a vertical direction. Therefore, overall, the formation is probably best characterized as a poor aquifer.

2.1.2 Rocks of Pavits Springs

2.1.2.1 Extent and Thickness

Rocks of Pavits Spring are exposed at the surface in the southern and southwestern portions of Frenchman Flat (Hinrichs, 1968; and Barnes *et al.*, 1982). Small isolated outcrops are also present southwest of Frenchman Flat in Rock Valley and just south of Skull Mountain and Little Skull Mountain (Maldonado, 1985) (*Figure 1-1*). Three drill holes in the region have encountered Rocks of Pavits Spring or similar rocks in the same general stratigraphic position. Drill hole UE-5m in extreme southwestern Frenchman Flat bottomed in Rocks of Pavits Spring after penetrating 68 m (224 ft) of the formation (Healy *et al.*, 1967). Five hundred and four meters (1,654 ft) of Rocks of Pavits Spring were encountered in Test Well F located east of Skull Mountain and approximately 6.5 kilometers (km) (4 miles [mi]) west of UE-5m (Carroll, 1963). Just east of Yucca Mountain, UE-25p#1 encountered 371 m (1,217 ft) of Tertiary rocks older than the Crater Flat Group, including 33 m (108 ft) of sedimentary rocks and tuff very similar to Rocks of Pavits Spring and in the same general stratigraphic position (Carr *et al.*, 1986).

Surface exposures indicate that the distribution of the Rocks of Pavits Spring may be restricted to the vicinity of the northeast-striking Rock Valley fault system. This is consistent with the likely possibility that deposition of the Rocks of Pavits Spring was associated with strike-slip movement along the Rock Valley fault system. Bohannon (1984) found similar associations between strike-slip faults in the Lake Mead region and deposition of portions of the possibly partly correlative Horse Spring Formation. Because gravity and aeromagnetic data indicate that the Rock Valley fault continues northeastward beneath the southern portion of Frenchman Flat (Grauch and Hudson, 1995) (*Figure 1-1*), it is likely that the Rocks of Pavits Spring underlie the southern portion of Frenchman Flat.

The occurrence of the Rocks of Pavits Spring in drill hole Test Well F and similar rocks in drill hole UE-25p#1 suggests that the Rocks of Pavits Spring may extend a considerable distance north of the Rock Valley fault system. Therefore, the Rocks of Pavits Spring may extend as far north as the central and northern portions of Frenchman Flat. However, it is likely that any Rocks of Pavits Spring that are present beneath northern Frenchman Flat are relatively thin. This conclusion is based on the fact that very few rocks similar to the Rocks of Pavits Spring are exposed at the surface north of Frenchman Flat and none have been recognized in drill holes in Yucca Flat. (As will be discussed below, the older Tertiary rocks north of Frenchman Flat are coeval, but not lithologically correlative with the Rocks of Pavits Spring.)

Like the Rocks of Winapi Wash, the thickness of the Rocks of Pavits Spring seems to differ considerably throughout the area. Barnes *et al.* (1982) reported up to 548+ m (1,800+ ft) of the formation in the southern portion of Frenchman Flat. In the vicinity of Hampel Wash, Hinrich (1968) measured over 1,067 m (3,500 ft) of Rocks of Pavits Spring. However, like the Rocks of Winapi Wash, numerous faults in the area and the lateral discontinuous nature of individual units within the Rocks of Pavits Spring make estimates of formation thickness very uncertain. Beneath the central portion of Frenchman Flat, gravity data (Wahl, 1995) and numerous cross sections constructed through the area generally constrain the thickness to about 300 m (985 ft) (Drellack and Prothro, 1997).

2.1.2.2 Age and Correlation

Evidence suggests that most of the Rocks of Pavits Spring are older than volcanic rocks of the Crater Flat Group which were deposited between 13.5 and 13.1 million years ago (Minor *et al.*, 1993). South of Skull Mountain and Little Skull Mountain and along Hampel Wash, volcanic rocks of the Crater Flat Group overlie Rocks of Pavits Spring. In drill hole UE-5m, Rocks of Pavits Spring are also overlain by volcanic rocks of the Crater Flat Group. In addition, a sequence of sedimentary rocks in drill hole UE-25p#1 is overlain by pre-Crater Flat tuffs of the Tram Ridge Group (~14.0 million years old [Sawyer *et al.*, 1994]) (Warren, in preparation).

Tuffs from the upper part of the Rocks of Pavits Spring have been found to be approximately 12 to 13 million years old (Yount, personal communication, 1996). Thus, in places the upper portion of the formation may be the same age or slightly younger than the Crater Flat Group.

Deposition of the Rocks of Pavits Spring appears to have been at least partly contemporaneous with volcanic activity of the SWNVF which commenced approximately 15.5 million years ago (Warren, personal communication, 1996). The abundance of tuff and tuffaceous debris throughout the Rocks of Pavits Spring, including multiple discrete ash-flow tuffs, suggests a nearby volcanic source. Due to their proximity, the calderas of the SWNVF are the most likely source for the tuffaceous material. Also, south of Skull Mountain and Little Skull Mountain, Lithic Ridge Tuff (14.0 million years old [Sawyer *et al.*, 1994]) of the Tram Ridge Group is intercalated with the formation (Maldonado, 1985). Furthermore, the sequence of sedimentary rocks in drill hole UE-25p#1 overlies ash-flow tuff of the Tub Spring Tuff (14.9 million years old [Sawyer *et al.*, 1994]) (Warren, in preparation).

Although the lower portion of the Rocks of Pavits Spring includes rocks older than SWNVF activity (more than 15.5 million years old) (Warren, personal communication,

1996; and Sawyer, personal communication, 1996), the formation is probably not older than about 18 million years. This is suggested by the occurrence of an ash-flow tuff in the lower portion of the formation that was dated at 15.8 million years, and by the presence of conglomerates containing volcanic clasts as young as 18.3 million years old (Yount, personal communication, 1996). However, the age of the base of the formation is much less constrained than the age of the formation top.

Because much of the Rocks of Pavits Spring were deposited contemporaneously with SWNVF activity, the formation probably interfingers to the north and northwest with coeval volcanic units, including pre-Crater Flat volcanic rocks north of Frenchman Flat (Figure 2-2). Consequently, the ratio of sedimentary rocks to primary volcanic rocks within the section decreases to the north and northwest.

The formation may correlate in part with the Horse Spring Formation in the Lake Mead region. The Horse Spring Formation generally consists of interbedded clastic rocks ranging from claystone to conglomerate, limestone, dolostone, evaporites, and tuff deposited in a lacustrine to marginal lacustrine environment between 11 and 20 million years ago (Bohannon, 1984). Age determinations from units designated as Horse Spring Formation by Stewart and Carlson (1978) that are exposed between the NTS and Lake Mead suggest that these rocks may also correlate in part with the Rocks of Pavits Spring (Yount, personal communication, 1996).

2.1.2.3 Lithology and Hydraulic Character

The Rocks of Pavits Spring form a diverse assemblage of interbedded volcanic and sedimentary rocks deposited at least partly contemporaneously with SWNVF volcanic activity in a predominately lacustrine and fluvial environment. Specific rock types observed during field reconnaissance include nonwelded to partially welded ash-flow tuffs, ash-fall tuffs, reworked tuffs, shale, tuffaceous and argillaceous sandstone, conglomerate, and limestone. In the southern portion of Frenchman Flat, Barnes *et al.* (1982) reported zeolitized tuff, limestone, and tuffaceous mudstone, siltstone, sandstone, and conglomerate. Hinrichs (1968) described similar rocks in the Rocks of Pavits Spring in the southwest portion of Frenchman Flat. The very tuffaceous character of the formation is diagnostic.

The formation is bedded and poorly exposed, forming an undulating, hummocky topography, characteristic of soft and poorly consolidated material (Figures 2-3 and 2-4). At many exposures of the formation, the rocks form frothy, rounded exposures consisting of very argillaceous and tuffaceous sandstone and reworked tuff. Many of the units,

Figure 2-2. Schematic cross section from Hampel Wash to Nye Canyon.

Figure 2-3. Exposure of Rocks of Pavits Spring showing the bedded nature of the formation.

Figure 2-4. Exposure of Rocks of Pavits Spring showing the undulating, hummocky topography characteristics of the formation.

including the conglomerates and limestones, appear to be laterally discontinuous, and of limited extent. Sedimentary structures, such as ripple marks, cross bedding, and graded bedding, are common throughout the formation.

The very tuffaceous character of the formation increases the likelihood that much of the formation may be zeolitized or argillized below the water table, thus significantly reducing permeability. For example, in drill holes UE-5m and Test Well F which encountered the formation below the water table, tuffs and tuffaceous sedimentary rocks were at least partially zeolitized.

The soft and bedded nature of much of the formation probably precludes development of extensive fracture systems. Fractures were observed in outcrops, particularly in the more indurated units such as limestones, well-cemented sandstones, and partly welded tuffs. However, the majority of these fractures were found to terminate at the contacts with softer units. In addition, many of the fractures observed were partially to completely filled with secondary quartz.

In summary, the very tuffaceous character of the formation and the abundance of fine-grained clastic rocks probably impart confining unit properties to the formation as a whole. However, the occurrence of fractured limestone and coarser clastic rocks within the formation probably increases to some extent the ability for the formation to transmit groundwater. Overall, the formation is probably best characterized as a confining unit. However, aquifer-type rocks present within the formation probably cause the formation to be a less effective confining unit than the overlying TCU which consists almost exclusively of zeolitized tuff.

2.2 Pre-Crater Flat Volcanic Rocks North of Frenchman Flat

In the southern Halfpint Range north of Frenchman Flat, Hinrichs and McKay (1965) designated a sequence of volcanic rocks directly overlying the pre-Tertiary rocks as Tuff of Pavits Spring (*Figure 2-1*). Later, Frizzell and Shulters (1990) included these rocks in a Miocene- and Oligocene-age compilation unit they designated as "sedimentary and tuffaceous sedimentary rocks, undivided." This compilation unit also included rocks south and southwest of Frenchman Flat formerly mapped as Rocks of Pavits Spring and the Horse Spring Formation (Barnes *et al.*, 1982; Hinrich, 1968; Maldonado, 1985). Most recently, Wahl *et al.* (1996) designated these rocks north of Frenchman Flat as the Bullfrog Tuff of the Crater Flat Group. However, sampling of these rocks by the authors

and others (Warren, personal communication, 1996; Sawyer, personal communication, 1996) indicates the presence of Tertiary volcanic rocks older than the Crater Flat Group. For this report, Tertiary-age volcanic rocks older than the Crater Flat Group that occur in the southern Halfpint Range north of Frenchman Flat will be called pre-Crater Flat volcanic rocks. Field sampling in the area indicates that these rocks consist of early volcanic deposits of the SWNVF, including beds 4JK of the Tunnel Formation and the Redrock Valley Tuff (Warren, personal communication, 1996; Sawyer, personal communication, 1996).

2.2.1 Extent and Thickness

Tuffs of the Crater Flat Group (mostly Bullfrog Tuff) and pre-Crater Flat volcanic rocks are extensively exposed in the southern portion of the Halfpint Range north of Frenchman Flat (Wahl *et al.*, 1996; Warren, personal communication, 1996; Sawyer, personal communication, 1996). Together, these rocks probably have a maximum thickness of at least 223 m (730 ft) (Hinrichs and McKay, 1965). Tuffs of the Crater Flat Group, specifically the Bullfrog Tuff, may represent much of this thickness (Sawyer, personal communication, 1996). However, the geology in the area is complex, and additional field and petrographic work are required for a detailed understanding of the volcanic stratigraphy of the area (Warren, personal communication, 1996).

Pre-Crater Flat volcanic rocks are probably present beneath the northern portion of Frenchman Flat. However, as discussed in Section 2.1.2.2, these rocks interfinger with coeval tuffaceous sedimentary rocks of the Rocks of Pavits Spring beneath the central portion of Frenchman Flat (*Figure 2-2*).

2.2.2 Age and Correlation

The pre-Crater Flat volcanic rocks north of Frenchman Flat are probably no older than about 15.5 million years (Warren, personal communication, 1996), making them approximately the same age as, and contemporaneous with, much of the Rocks of Pavits Spring (generally Middle Miocene).

Lenses of conglomerate are intercalated with the volcanic rocks exposed in the southern Halfpint Range north of Frenchman Flat (*Figure 2-5*). Although it is unclear whether the conglomerate lenses are intercalated with the Bullfrog Tuff, pre-Crater Flat volcanic rocks, or both, a lens of conglomerate can be seen to truncate a thin, green peralkaline ash bed in Nye Canyon (*Figure 2-6*). Thin, green peralkaline ash beds like this one are common within the lower portion of beds 4JK of the (pre-Crater Flat) Tunnel Formation (Warren and Sawyer, 1993). If the conglomerates are pre-Crater Flat in age, then they could

Figure 2-5. Conglomerate lenses intercalated with tuff in Nye County, north of Frenchman Flat.

Figure 2-6. Conglomerate lens truncating green peralkaline ash bed in Nye Canyon (wooden rule is 1.8 m [6 ft] in length).

represent a fluvial system that flowed south into the basin where the Rocks of Pavits Spring were accumulating. Lithologies of boulders within the conglomerates of the Rocks of Pavits Spring suggest a northern source (Barnes *et al.*, 1982).

The intercalated conglomerates in Nye Canyon may correlate in part with the older clastic rocks of Tschanz and Pampeyan (1970) exposed to the east around the Buried Hills (Figure 1-1). Besides having similar lithology, the conglomerates may be the same general age. Tschanz (1960) reported that Miocene or younger lacustrine limestone conformably overlies the older clastic rocks, indicating that at least some of the older clastic rocks are Miocene in age. If the intercalated conglomerates in Nye Canyon correlate in part with the older clastic rocks of Tschanz and Pampeyan (1970), then the conglomerates in Nye Canyon probably represent the interfingering of the older clastic rocks with coeval volcanic rocks of the SWNVF. This stratigraphic relationship is similar to that believed to occur to the southwest where the Rocks of Pavits Spring interfinger to the north and northwest with coeval volcanic units. Thus, the Rocks of Pavits Spring may correlate in part with the older clastic rocks of Tschanz and Pampeyan (1970).

2.2.3 Lithology and Hydraulic Character

The Crater Flat Group and pre-Crater Flat volcanic rocks north of Frenchman Flat consist predominantly of primary volcanic deposits such as ash-fall tuffs and nonwelded to partially welded ash-flow tuffs erupted from sources within the SWNVF (Warren, personal communication, 1996). Hinrichs and McKay (1965) reported "Tuff of Pavits Spring" as being locally conglomeratic, carbonaceous, and fossiliferous. In the vicinity of Nye Canyon, the authors of this report observed lenses of conglomerate intercalated with the tuffs. However, sedimentary rocks and sedimentary structures are much less common within the older Tertiary volcanic rocks in Nye Canyon than they are in the Rocks of Pavits Spring south and southwest of Frenchman Flat.

Although the Crater Flat Group and older volcanic rocks north of Frenchman Flat are mostly vitric at the surface, beneath the water table the rocks are likely to be zeolitized and thus act as a confining unit. This is exactly the case in Yucca Flat, where correlative volcanic units are highly zeolitized below the water table and form a tuff confining unit in the area. The intercalated sedimentary rocks, such as the conglomerates, probably have the capability of transmitting groundwater. However, these rocks appear to compose only a small fraction of the total geologic section in the area and are of limited lateral extent. Thus, the sedimentary rocks probably have only a minor influence on the hydraulic character of the section as a whole.

3.0 HYDROSTRATIGRAPHY

In order to model groundwater flow within the Frenchman Flat CAU, it is necessary to divide the rocks within and beneath the Frenchman Flat CAU into hydrostratigraphic units based on stratigraphic position and similar hydrogeologic characteristics. This allows for the construction of cross sections and unit-extent maps of aquifers and confining units which are used by the modeling program to determine and predict groundwater flow within the Frenchman Flat CAU.

Winograd and Thordarson (1975) included the Miocene and Oligocene-age sedimentary rocks south of Frenchman Flat (Rocks of Pavits Spring and Rocks of Winapi Wash in this report) within a regional hydrogeologic unit termed the tuff aquitard. This unit included all the tuffs and associated sedimentary rocks older than the Paintbrush Group (Winograd and Thordarson 1975). For this report, the Rocks of Winapi Wash and Rocks of Pavits Spring are grouped into a single distinct hydrostratigraphic unit called the Volcaniclastic Confining Unit (VCU). (This designation is not new and has been used previously in UGTA hydrogeologic work.) The two formations are grouped together because of their stratigraphic position and similar lithologic and hydraulic characteristics, which are different from those of overlying and underlying formations. The term volcaniclastic is used as part of the name for this unit because of the abundance of tuffaceous sedimentary rocks within the Rocks of Pavits Spring.

Although the Rocks of Winapi Wash may have the overall character of a poor aquifer, the VCU is designated a confining unit because the Rocks of Pavits Spring, which probably have the overall character of a confining unit, appear to be thicker and more extensive within the Frenchman Flat CAU than the Rocks of Winapi Wash. However, the inclusion of the Rocks of Winapi Wash within this hydrostratigraphic unit along with aquifer-like rocks within the Rocks of Pavits Spring, probably increases to some extent the "leakiness" of this confining unit.

The VCU is probably present beneath most of the southern and central portions of Frenchman Flat where it is estimated to be around 400 m (1,300 ft) thick. The unit may extend as far north as the northern portion of the basin. However, beneath the central portion of Frenchman Flat, the VCU probably begins to interfinger with coeval zeolitized volcanic rocks which, along with overlying volcanic rocks, form the TCU, the major confining unit in the northern portion of Frenchman Flat (*Figure 2-2*). (These coeval volcanic rocks are the zeolitized equivalent of the pre-Crater Flat volcanic rocks exposed

north of Frenchman Flat in the southern portion of the Halfpint Range. However, the pre-Crater Flat volcanic rocks are included within the TCU because their lithologic and hydraulic character are similar to the overlying Crater Flat Group and younger volcanic rocks that make up the majority of the TCU.) Therefore, if the VCU is present beneath the northern portion of the basin, it is probably relatively thin (less than 60 m [200 ft]).

The VCU overlies the LCA, the regional aquifer beneath Frenchman Flat. The VCU is, in turn, typically overlain by younger zeolitized volcanic rocks that form the tuff confining unit which underlies the volcanic and alluvial aquifers of the basin (Drellack and Prothro, 1997). The position of the VCU directly overlying the LCA could have important hydrogeologic implications for Frenchman Flat. Aeromagnetic data indicate that volcanic rocks may not be present beneath the central and eastern portions of Frenchman Flat (Grauch and Hudson, 1995). If this is the case, then the possibility exists that the alluvial aquifer directly overlies the LCA, thus providing a direct pathway for water-borne radionuclides to enter the LCA. However, if the VCU is present beneath the central portion of Frenchman Flat as the conclusions of the current study suggest, then the VCU could help retard the movement of water-borne contaminants into the LCA.

4.0 RECOMMENDATIONS FOR FURTHER STUDY

Most of what is currently known about the older Tertiary sedimentary rocks in the southern portion of the NTS is compiled in this report, and these data were analyzed to infer the general hydrogeologic character of these units. However, many questions and uncertainties still exist with regard to the specific hydrogeologic characteristics of these rocks. Additional detailed mapping, petrographic analysis, and age-dating of these units would greatly improve the understanding of the extent, thickness, stratigraphic relationships, and hydraulic character of these rocks.

5.0 SUMMARY

Tertiary sedimentary rocks that are exposed south and southwest of Frenchman Flat are divided into two formations. The older Oligocene-age Rocks of Winapi Wash consist of interbedded limestone, claystone, siltstone, sandstone, conglomerate, and minor intercalated volcanic tuff. The overlying Miocene-age Rocks of Pavits Spring consist of interbedded volcanic and sedimentary rocks, including nonwelded to partially welded ash-flow tuffs, ash-fall tuffs, reworked tuffs, shale, tuffaceous and argillaceous sandstone, tuffaceous conglomerate, and limestone. Together, these two formations form a single hydrostratigraphic unit designated here as the Volcaniclastic Confining Unit. This hydrostratigraphic unit is considered to be a confining unit because of the abundance of tuffaceous rocks (which tend to become zeolitized below the water table) and fine-grained clastic rocks. These rocks severely limit the ability of the unit to transmit groundwater. However, the presence of aquifer-like rocks within the Volcaniclastic Confining Unit probably increases the "leakiness" of this confining unit. The Volcaniclastic Confining Unit is present beneath the southern and central Frenchman Flat where it directly overlies the regional Lower Carbonate Aquifer. The Volcaniclastic Confining Unit reaches an estimated thickness of 400 m (1,300 ft) beneath the central portion of Frenchman Flat, but thins to north and northwest as it interfingers with volcanic rocks of the tuff confining unit.

Older Tertiary-age rocks (pre-Crater Flat volcanic rocks) that are generally the same age as portions of the Rocks of Pavits Spring are exposed north of Frenchman Flat in the southern portion of the Halfpint Range. These rocks consist mostly of primary volcanic rocks such as ash-fall tuffs and nonwelded to partially welded ash-flow tuffs. Although mostly vitric at the surface, these rocks are probably zeolitized below the water table, as they are beneath the southern portion of Yucca Flat. These older, Tertiary-age rocks form the basal portion of the Tuff Confining Unit beneath the northern portion of Frenchman Flat. The Tuff Confining Unit has an estimated maximum thickness of about 244 m (800 ft) beneath the northern portion of Frenchman Flat, but thins to the south as the basal portion of the unit interfingers with coeval rocks within the Volcaniclastic Confining Unit.

The information presented in this report has been applied to the concurrent Frenchman Flat Corrective Action Unit modeling effort, specifically in the construction of hydrostratigraphic cross sections and unit-extent maps.

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Appendix A

Field Data

Table A-1 Field Data

Outcrop Number	Northing (ft)	Easting (ft)	Date	General Geology	Outcrop Samples	Sample Lithology	Photographs	Photograph Description	Sketch (yes/no)
384-Tpa-1	795950	730050	10/17/96	Crater Flat Group and older volcanic rocks - Large lens of conglomerate within tuff.	384-Tpa-1-1	Nonwelded tuff	384-Tpa-1-A	Station	yes
					384-Tpa-1-2	Conglomerate	384-Tpa-1-B	Green bedded tuff	
					384-Tpa-1-3	Nonwelded tuff	384-Tpa-1-C	Cobble lens	
					384-Tpa-1-4	Bedded tuff			
					384-Tpa-1-5	Nonwelded tuff			
384-Tpa-2	796400	730300	10/17/96	Crater Flat Group and older volcanic rocks - Tuff and conglomerate lenses with cut and fill features.	None	NA	384-Tpa-2-A	Station	yes
384-Tpa-3	797600	731000	10/17/96	Crater Flat Group and older volcanic rocks - Tuff and paleocolluvium overlying Eureka Quartzite	384-Tpa-3-1	Paleocolluvium	384-Tpa-3-A	Station	no
					384-Tpa-3-2	Nonwelded tuff	384-Tpa-3-B	Paleocolluvium	
					384-Tpa-3-3	Nonwelded tuff			
384-Tpa-4	~798000	~731900	10/17/96	Crater Flat Group and older volcanic rocks - Tuff overlying Ely Springs Dolomite (?)	384-Tpa-4-1	Nonwelded tuff	384-Tpa-4-A	Station	yes
					384-Tpa-4-2	Nonwelded tuff	384-Tpa-4-B	Conglomerate lenses	
					384-Tpa-4-3	Nonwelded tuff			

Table A-1 (continued)

Outcrop Number	Northing (ft)	Easting (ft)	Date	General Geology	Outcrop Samples	Sample Lithology	Photographs	Photograph Description	Sketch (yes/no)
384-Tpan-1	787250	727950	10/17/96	Crater Flat Group and older volcanic rocks - Bedded tuff	384-Tpan-1-1 384-Tpan-1-2 384-Tpan-1-3	Bedded tuff Bedded tuff Bedded tuff	384-Tpan-1-A	Station	yes
384-Tpan-2	788850	727950	10/17/96	Crater Flat Group and older volcanic rocks - Bedded Tuff overlain by alluvium.	None	NA	384-Tpan-2-A	Station	yes
384-Tpan-3	789100	728550	10/17/96	Crater Flat Group and older volcanic rocks - Nonwelded ash-flow tuff.	384-Tpan-3-1 384-Tpan-3-2	Nonwelded ash-flow tuff Silicified branch-like features	384-Tpan-3-A 384-Tpan-3-B	Station Branch-like features	yes
726-Tpac-1	721600	691700	10/10/96	Rocks of Pavits Spring - Conglomerate	726-Tpac-1-1	Conglomerate	726-Tpac-1-A 726-Tpac-1-B	Closeup of conglomerate Station	yes
726-Tpag-1	722050	692050	10/10/96	Rocks of Pavits Spring - Ash-flow tuff and bedded tuff	726-Tpag-1-1	Partially welded ash-flow tuff	726-Tpag-1-A	Station	yes
726-Tpal-1	724250	684150	10/10/96	Rocks of Pavits Spring - Stromatolitic limestone	726-Tpal-1-1	Limestone	726-Tpal-1-A	Station	no

Table A-1 (continued)

Outcrop Number	Northing (ft)	Easting (ft)	Date	General Geology	Outcrop Samples	Sample Lithology	Photographs	Photograph Description	Sketch (yes/no)
726-Tpas-1	725500	690350	10/10/96	Rocks of Pavits Spring - Interbedded reworked tuffs and minor dolostone.	726-Tpas-1-1	Reworked tuff	726-Tpas-1-A	Closeup of lower tuff	yes
					726-Tpas-1-2	Reworked tuff	726-Tpas-1-B	Station	
					726-Tpas-1-3	Reworked tuff			
					726-Tpas-1-4	Dolostone			
726-Tpas-2	721600	694850	11/6/96	Rocks of Pavits Spring - Interbedded tuffaceous sandstones and reworked tuffs	726-Tpas-2-1	Reworked tuff	726-Tpas-2-A	Steeply dipping beds	yes
					726-Tpas-2-2	Reworked tuff	726-Tpas-2-B	Station	
					726-Tpas-2-3	Sandstone	726-Tpas-2-C	Looking NW from station	
							726-Tpas-2-D	Looking NW from station	
726-Tpas-3	722000	694250	11/6/96	Rocks of Pavits Spring - Brown sandstone ledge overlying shale	726-Tpas-3-1	Sandstone	726-Tpas-1-A	Brown sandstone	yes
					726-Tpas-3-2	Shale	726-Tpas-1-B	Underlying shale	
726-Tpas-4	723400	693900	11/6/96	Rocks of Pavits Spring - Conglomerate with slickensides.	726-Tpas-4-1	Conglomerate	None	NA	no

Table A-1 (continued)

Outcrop Number	Northing (ft)	Easting (ft)	Date	General Geology	Outcrop Samples	Sample Lithology	Photographs	Photograph Description	Sketch (yes/no)
726-Tpfu-1	724150	684000	10/10/96	Rocks of Pavits Spring - Nonwelded tuff to bedded tuff near base	726-Tpfu-1-1	Reworked tuff	726-Tpfu-1-A 726-Tpfu-1-B	Station Looking west	no
1197-Th-1	714800	710300	10/17/96	Rocks of Winapi Wash - Interbedded tuff, limestone, and sandstone	1197-Th-1-1 1197-Th-1-2 1197-Th-1-3 1197-Th-1-4	Reworked tuff Limestone Limestone Sandstone	1197-Th-1-A	Tuff and overlying limestone	no
1197-Th-2	714800	698900	11/6/96	Rocks of Winapi Wash - Interbedded limestone and conglomerate	1197-Th-2-1 1197-Th-2-2	Limestone Limestone	1197-Th-1-A 1197-Th-1-B	Station Closeup of limestone	yes
1197-Tpas-1	723950	696800	11/6/96	Rocks of Pavits Spring - Interbedded tuff and sandstone	1197-Tpas-1-1 1197-Tpas-1-2 1197-Tpas-1-3	Reworked tuff Bedded tuff Sandstone	1197-Tpas-1-A	Upper tuff	yes
1197-Tpas-2	724400	696600	11/6/96	Rocks of Pavits Spring - Cross-bedded sandstone overlying white tuff	1197-Tpas-2-1 1197-Tpas-2-2	Nonwelded tuff Reworked tuff	1197-Tpas-2-A	Station	yes

Table A-1 (continued)

Outcrop Number	Northing (ft)	Easting (ft)	Date	General Geology	Outcrop Samples	Sample Lithology	Photographs	Photograph Description	Sketch (yes/no)
1197-Tpas-3	724950	697000	11/6/96	Rocks of Pavits Spring - Interbedded tuff and conglomerate	1197-Tpas-3-1	Ash-fall tuff	None	NA	no
					1197-Tpas-3-2	Conglomerate			
1197-Tpat-1	716350	698700	11/6/96	Rocks of Pavits Spring - Interbedded sandstone and tuff	1197-Tpat-1-1	Reworked tuff	1197-Tpat-1-A	Station	yes
					1197-Tpat-1-2	Sandstone	1197-Tpat-1-B	Sandstone bed (1197-Tpat-1-3)	
					1197-Tpat-1-3	Sandstone			
1197-Tpat-2	716500	698500	11/6/96	Rocks of Pavits Spring - Interbedded tuff and sandstone	1197-Tpat-2-1	Reworked lapilli tuff	1197-Tpat-2-A	Station	no
					1197-Tpat-2-2	Sandstone	1197-Tpat-2-B	Cross-bedding in reworked lapilli tuff	
					1197-Tpat-2-3	Reworked tuff	1197-Tpat-2-C	Reworked tuff	

Appendix B

Detailed Sample Descriptions

DETAILED SAMPLE DESCRIPTIONS

Note: The following descriptions refer to outcrop samples that generally show only minor alteration. However, where correlative or similar rocks occur below the water table, alteration is likely to be more extensive, and hydraulic properties considerably different. (See discussions on pages 2-4, 2-13, and 2-19 of this report.)

Sample:	384-Tpa-1-1	Location:	N795950; E730050
Date Described:	10-31-96	Geologist:	L. B. Prothro
Lithologic Description:	Nonwelded Tuff: Moderate-yellowish-brown; vitric to weakly zeolitic; minor white pumice, mostly 1 - 2 mm in size; minor to common felsic phenocrysts of feldspar and lesser quartz; minor mafic minerals of biotite and hornblende; minor various- colored lithic fragments less than 5 mm in size; poorly indurated.		
Geologic Notes:	Crater Flat Group and older volcanic rocks. Sample is from just below conglomerate lens. Unit from which sample was taken appears massive (not bedded), with <u>no</u> sedimentary structures (cross-bedding or graded bedding). Possibly Tn4JK.		
Hydrogeologic Notes:	Moderate vitric-tuff aquifer properties - moderate porosity and permeability.		

Sample:	384-Tpa-1-2	Location:	N795950; E730050
Date Described:	10-31-96	Geologist:	L. B. Prothro
Lithologic Description:	Conglomerate: Moderate-yellowish-brown; moderately indurated; paraconglomeratic; 40 - 50% poorly sorted, subrounded, very fine pebbles to boulders of pre-Tertiary quartzite clasts and lesser pre-Tertiary carbonate and chert clasts; 40 - 50% tuffaceous matrix that appears partially zeolitized/argillized; moderately calcareous; calcite and zeolite/clay cement.		
Geologic Notes:	Crater Flat Group and older volcanic rocks. A 2-m-thick lens of conglomerate within a bedded tuff sequence that appears to be equivalent to Tn4JK.		
Hydrogeologic Notes:	Moderate aquifer properties - moderate porosity and permeability. Poor sorting and partial zeolitization/argillation of matrix reduces aquifer properties.		

Detailed Sample Descriptions (continued)

Sample: 384-Tpa-1-3 **Location:** N795950; E730050

Date Described: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: **Nonwelded Tuff:** Pale-yellowish-brown to moderate yellowish-brown; vitric; common rounded pumice; minor to common felsic minerals of feldspar and quartz showing some frosting; rare mafic minerals of hornblende and lesser biotite; rare greenish-black glass shards; granular fabric; very fine-grained to fine-grained; poorly indurated.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample is from tuff sequence above lens of conglomerate (384-Tpa-1-2). Sample may be slightly reworked. However, no sedimentary structures were observed in sample or outcrop.

Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Sample: 384-Tpa-1-4 **Location:** N795950; E730050

Date Described: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: **Bedded Tuff:** Moderate- to dark-greenish-yellow; vitric; pumiceous, very abundant pumice throughout; very rare feldspar phenocrysts; mafic minerals conspicuously absent; rare lithic fragments less than 1 mm in size; very abundant greenish-black cusped glass shards; granular fabric; very coarse-grained; poorly indurated. Two ~5-mm-thick, medium-gray, very-fine-grained ash beds are present in sample.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample is from a conspicuous 2-ft-thick greenish-colored bed that occurs within a thick sequence of light-brownish-colored tuff that contains large lenses of conglomerate. One of these conglomerate lenses truncates the green bed at this location. Green unit is probably a comenditic tephra in the lower part of Tn4JK.

Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 384-Tpa-1-5 **Location:** N795950; E730050

Date Described: 11-04-96 **Geologist:** L. B. Prothro

Lithologic Description: **Nonwelded Tuff:** Pale-yellowish-brown to dark-yellowish-brown; vitric; minor rounded pumice; minor to common felsic minerals of feldspar and quartz showing some rounding and frosting; common mafic minerals of hornblende (showing some rounding) and lesser biotite; minor lithic fragments less than 2 mm in size; minor to common greenish-black cusped glass shards; granular fabric; mostly very fine- to fine-grained but poorly sorted, with some very coarse-grained material (pumice); poorly indurated; moderately calcareous.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample taken adjacent to unusual cobble/boulder lens. Sample may be slightly reworked. Although associated with small (0.5 m in length and one clast-size in thickness) lens of rounded quartzite cobbles/boulders no sedimentary structures were observed in the adjacent tuffaceous rocks. Probably Tn4JK.

Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Sample: 384-Tpa-3-1 **Location:** N797600; E731000

Date Described: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: **Paleocolluvium (sandstone):** Moderate-reddish-brown to dark-reddish-brown; moderately indurated; mostly fine- to medium-grained, subangular to subrounded, poorly sorted sand with 10 - 20% angular Eureka Quartzite fragments up to 7 cm in size; weakly to moderately calcareous; clay and calcite cement.

Geologic Notes: Directly overlies the Eureka Quartzite and is overlain by tuffs similar to 384-Tpa-3-1 and 384-Tpa-3-2. Appears to be thin (less than 3 - 4 m) and of very limited extent at this location.

Hydrogeologic Notes: Probably poor aquifer properties due to clay cement, angularity, and poor sorting.

Detailed Sample Descriptions (continued)

Sample: 384-Tpa-3-2 **Location:** N797600; E731000

Date Described: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: **Nonwelded Tuff:** Yellowish-gray (5Y 8/1); vitric to very weakly zeolitic; appears very pumiceous; very abundant felsic minerals of quartz and lesser feldspar; abundant to very abundant mafic minerals of biotite and slightly less hornblende; rare grayish-red-purple tuffaceous lithic fragments less than 2 mm in size; granular fabric; coarse-grained; poorly indurated.

Geologic Notes: Crater Flat Group and older volcanic rocks. Unit directly overlies Eureka Quartzite. The steep dip (30 - 35 degrees to the SE) of this unit (underlying Eureka dips ~10 degrees NW); slickensides in the adjacent Eureka; and a subtle, linear contact between the units suggest a possible fault contact. However, the overall appearance of the contact appears depositional. A thin veneer of paleocolluvium (384-Tpa-3-1) is exposed nearby and appears to lie between the Eureka Quartzite and the nonwelded tuff (384-Tpa-3-2) in places. Possibly Tn3A or Tn4JK (most likely).

Hydrogeologic Notes: Good vitric-tuff aquifer - high porosity and permeability.

Sample: 384-Tpa-3-3 **Location:** N797600; E731000

Date: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: **Nonwelded Tuff:** Pale-yellowish-brown; vitric to very weakly zeolitic; very pumiceous with very abundant pumice throughout; very abundant felsic minerals of feldspar and quartz; common to abundant mafic minerals of biotite and slightly less hornblende and magnetite; minor, mostly grayish-red-purple tuffaceous lithic fragments less than 2 mm in size; granular fabric; medium- to coarse-grained; poorly indurated.

Geologic Notes: Crater Flat Group and older volcanic rocks. Unit forms a large monolith and is petrographically very similar to underlying 384-Tpa-3-2. Possibly Tn3A or Tn4JK (most likely).

Hydrogeologic Notes: Good vitric-tuff aquifer - high porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 384-Tpa-4-1 **Location:** N798000; E731900

Date Described: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: Nonwelded Tuff: Moderate-yellowish-brown; vitric to partially zeolitic/argillic; rare pumice; minor felsic phenocrysts of feldspar and quartz; common mafic minerals of hornblende and lesser biotite and magnetite; rare lithic fragments; calcareous; poorly indurated.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample taken from just above contact with Ely Springs Dolomite (?).

Hydrogeologic Notes: Moderate vitric-tuff aquifer properties - moderate porosity and permeability. Zeolitization/argillation reduces aquifer properties.

Sample: 384-Tpa-4-2 **Location:** N798000; E731900

Date Described: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: Nonwelded Tuff: Very similar to 384-Tpa-4-1; increase in the abundance of felsic phenocrysts to common in abundance; noncalcareous.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample taken approximately 1 m above sample 384-Tpa-4-1. Both samples appear to be from the same unit.

Hydrogeologic Notes: Same as 384-Tpa-4-1.

Detailed Sample Descriptions (continued)

Sample: 384-Tpa-4-3 **Location:** N798000; E731900

Date Described: 10-31-96 **Geologist:** L. B. Prothro

Lithologic Description: Nonwelded Tuff: Similar to samples 384-Tpa-4-1 and 384-Tpa-4-2; less vitric; slightly more indurated; weakly calcareous.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample taken approximately 1 m above sample 384-Tpa-4-2 and 2 m above sample 384-Tpa-4-1 and contact with Ely Springs Dolomite(?). All three samples are probably from the same nonwelded tuff unit. Approximately 7 m of this unit is exposed at station 384-Tpa-4 and contains large lenses of conglomerate similar to station 384-Tpa-1.

Hydrogeologic Notes: Same as samples 384-Tpa-4-1 and 384-Tpa-4-2.

Sample: 384-Tpan-1-1 **Location:** N787250; E727950

Date Described: 11-4-96 **Geologist:** L. B. Prothro

Lithologic Description: Bedded Tuff: Olive-gray; vitric; common to abundant pumice; very abundant felsic minerals of feldspar and quartz; very abundant biotite; rare to minor lithic fragments less than 1 mm in size; granular fabric; very fine- to fine-grained; poorly indurated.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample from a 1-ft-thick gray ash bed at base of exposure.

Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 384-Tpan-1-2 **Location:** N787250; E727950

Date Described: 11-4-96 **Geologist:** L. B. Prothro

Lithologic Description: **Bedded Tuff:** Very-light-gray to yellowish-gray; vitric; very coarsely pumiceous, individual pumice fragments difficult to distinguish; rare feldspar phenocrysts; very abundant biotite; lithic-rich, with common tuffaceous lithic fragments up to 1 - 2 cm in size; weakly calcareous; poorly indurated.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample from 1- to 2-ft-thick lithic-rich bed overlying gray ash bed (384-Tpan-1-1). Absence of quartz suggests sample may be Paintbrush Group.

Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Sample: 384-Tpan-1-3 **Location:** N787250; E727950

Date Described: 11-4-96 **Geologist:** L. B. Prothro

Lithologic Description: **Bedded Tuff:** Very-light-gray to yellowish-gray; vitric; very coarsely pumiceous, individual pumice fragments difficult to distinguish; common feldspar phenocrysts; very abundant biotite; rare tuffaceous lithic fragments less than 1 - 2 mm in size; poorly indurated.

Geologic Notes: Crater Flat Group and older volcanic rocks. Sample from 1- to 2-ft-thick very pumiceous bed overlying lithic-rich bed (384-Tpan-1-2). Absence of quartz suggests sample may be Paintbrush Group.

Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 384-Tpan-3-1 **Location:** N789100; E728550
Date Described: 11-4-96 **Geologist:** L. B. Prothro
Lithologic Description: Nonwelded Ash-Flow Tuff: Pale-brown; vitric; minor to common pumice; rare to minor feldspar phenocrysts; minor to common biotite; rare lithic fragments; poorly indurated.
Geologic Notes: Crater Flat Group and older volcanic rocks. Sample is from a massive nonwelded ash-flow tuff that appears to be extensive in the area. Absence of quartz suggests sample may be Paintbrush Group.
Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Sample: 384-Tpan-3-2 **Location:** N789100; E728550
Date Described: 11-4-96 **Geologist:** L. B. Prothro
Lithologic Description: None.
Geologic Notes: Sample is of silicified branch-like features within 384-Tpan-3-2. Probably of fumarolic origin.
Hydrogeologic Notes: NA

Sample: 726-Tpac-1-1 **Location:** N721600; E691700
Date Described: 11-4-96 **Geologist:** L. B. Prothro
Lithologic Description: **Conglomerate:** Light-brown (5YR 5/6); moderately indurated; mostly paraconglomeratic; 40 - 50% moderately to poorly sorted, subrounded, pebble- to boulder-size clasts of quartzite and much less chert; 50 - 60% poorly sorted, subangular, mostly fine- to medium-grained, slightly tuffaceous, moderately calcareous, sandy matrix; clay and calcite cement.
Geologic Notes: Rocks of Pavits Spring. Sample is from a 20-ft-thick lens of conglomerate.
Hydrogeologic Notes: Poor to moderate aquifer properties - low to moderate porosity and permeability. Poor sorting and clay reduces aquifer properties.

Detailed Sample Descriptions (continued)

Sample: 726-Tpag-1-1 **Location:** N722050; E692050

Date Described: 11-4-96 **Geologist:** L. B. Prothro

Lithologic Description: Nonwelded to Partially Welded Ash-Flow Tuff: Dusky-yellow; mostly zeolitic, partially devitrified; very abundant, conspicuously large (up to 3 mm) felsic phenocrysts of feldspar and lesser quartz; abundant mafic minerals of biotite and lesser hornblende; rare to minor tuffaceous lithic fragments; rare sphene; moderately indurated.

Geologic Notes: Rocks of Pavits Spring. Sample is from a 10-ft-thick ash-flow tuff unit under- and overlain by bedded tuff.

Hydrogeologic Notes: Very poor to poor aquifer properties - low to moderate porosity and low to very low permeability. Zeolitization of sample reduces aquifer properties.

Sample: 726-Tpal-1-1 **Location:** N724250; E684150

Date Described: 11-4-96 **Geologist:** L. B. Prothro

Lithologic Description: Limestone: Pale-yellowish-brown; well indurated; coarsely crystalline; stromatolitic; trace biotite; common Mn-oxide deposits; common small vugs generally less than 1 mm in diameter; very rough on weathered surfaces.

Geologic Notes: Sample from a 2- to 3-ft-thick freshwater limestone outcrop in the upper part of the Rocks of Pavits Springs.

Hydrogeologic Notes: Poor aquifer properties - low to moderate porosity and probably low permeability.

Detailed Sample Descriptions (continued)

Sample: 726-Tpas-1-1 **Location:** N75500; E690350
726-Tpas-1-2
726-Tpas-1-3

Date Described: 11-4-96 **Geologist:** L. B. Prothro

Lithologic Description: **Reworked Tuffs:** Pale-yellowish-brown to moderate-yellowish-brown; vitric to partially zeolitic; very abundant felsic phenocrysts of feldspar and quartz, with some showing slight rounding and frosting; abundant mafic minerals of biotite and hornblende; minor tuffaceous lithic fragments less than 1 mm in size; medium-grained, slight granular fabric in some samples; subtle cross-bedding and horizontal laminations.

Geologic Notes: Rocks of Pavits Spring. Samples are from a 20-ft-thick exposure consisting of a sequence of reworked tuffs. Each sample is from a different 1-ft-thick bed of reworked tuff. A thin (less than 1 ft thick) dolostone bed occurs at the top of the exposure (sample 726-Tpas-1-4).

Hydrogeologic Notes: Poor to moderate aquifer properties - low to moderate porosity and permeability. Partial zeolitization reduces aquifer properties.

Sample: 726-Tpas-1-4 **Location:** N75500; E690350

Date Described: 11-4-96 **Geologist:** L. B. Prothro

Lithologic Description: **Dolostone:** Moderate-yellowish-brown; finely crystalline to cryptocrystalline; silty.

Geologic Notes: Rocks of Pavits Spring. Sample is from a thin (less than 1 ft thick) dolostone bed occurring at the top of sequence of reworked tuffs (samples 726-Tpas-1-1 thru 4).

Hydrogeologic Notes: Poor aquifer properties - very low porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 726-Tpas-2-1 **Location:** N721600; E694850

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Reworked Tuff: Light-brown (5YR 6/4); partially zeolitic; common quartz and feldspar phenocrysts; minor mafic minerals of biotite and lesser hornblende; rare to minor lithic fragments; calcareous; poorly indurated; subtle stratification.

Geologic Notes: Rocks of Pavits Spring. Thickness approximately 1 ft, but is a single bed in a rather thick bedded sequence. Beds dip almost vertical due to drag along nearby fault.

Hydrogeologic Notes: Moderate aquifer properties - moderate porosity and permeability. Partial zeolitization probably reduces aquifer properties.

Sample: 726-Tpas-2-2 **Location:** N721600; E694850

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Reworked Tuff (Water-laid Ash-Fall): Pale-yellowish-brown; partially zeolitic; minor to common feldspar and quartz; minor mafic minerals of biotite (showing parallel alignment) and lesser hornblende; calcareous; poorly indurated and flaggy; very fine-grained.

Geologic Notes: Rocks of Pavits Spring. Thickness approximately 1 ft, but is a single bed in a rather thick bedded sequence. Beds dip almost vertical due to drag along nearby fault. Sample from flaggy weathering unit just below sample 726-Tpas-2-1.

Hydrogeologic Notes: Poor aquifer properties - low porosity and permeability. Partial zeolitization and small grain size reduce aquifer properties.

Detailed Sample Descriptions (continued)

Sample: 726-Tpas-2-3 **Location:** N721600; E694850

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Sandstone: Yellowish-gray (5Y 7/2) to light-olive-gray (5Y 5/2); poorly indurated to friable; medium-grained; moderately to well sorted; subangular to subrounded; tuffaceous with quartz and feldspar crystals, rock fragments, mafic minerals of biotite and hornblende, and zeolitic ash matrix; very calcareous; zeolite and calcite cement.

Geologic Notes: Rocks of Pavits Spring. Sample from an approximately 3-ft-thick bed at top of exposure.

Hydrogeologic Notes: Good aquifer properties - relatively high porosity and permeability.

Sample: 726-Tpas-3-1 **Location:** N724950; E697000

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Sandstone: Moderate-yellowish-brown; poorly indurated; coarse-grained; moderately to well sorted; subangular to subrounded; tuffaceous with quartz and feldspar crystals, rock fragments, mafic minerals of biotite and hornblende, and pumice fragments; calcareous; calcite cement.

Geologic Notes: Rocks of Pavits Spring. Sample from an approximately 3-ft-thick bed.

Hydrogeologic Notes: Good aquifer properties - relatively high porosity and permeability.

Sample: 726-Tpas-3-2 **Location:** N724950; E697000

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Shale: Light-olive; poorly indurated; fissile; calcareous; swells when wet.

Geologic Notes: Rocks of Pavits Spring. Thickness unknown. Sample from below 726-Tpas-3-1.

Hydrogeologic Notes: Confining unit properties.

Detailed Sample Descriptions (continued)

Sample: 726-Tpas-4-1 **Location:** N723400; E693900
Date Described: 11-21-96 **Geologist:** L. B. Prothro
Lithologic Description: **Conglomerate:** Moderate-reddish-brown to dark-reddish-brown; well indurated; orthoconglomeratic; 60 - 70% subrounded to rounded, well sorted, tuffaceous rock clasts averaging 2 - 3 mm in size; quartz grains also present; 30 - 40% fine sand and silt matrix; moderately calcareous; slickensides observed.
Geologic Notes: Rocks of Pavits Spring. Thickness approximately 3 - 4 ft. Sample from exposure adjacent to fault.
Hydrogeologic Notes: Moderate aquifer properties. Moderate porosity and permeability.

Sample: 726-Tpfu-1-1 **Location:** N724150; E684000
Date Described: 11-4-96 **Geologist:** L. B. Prothro
Lithologic Description: **Reworked Tuff:** Dusky-yellow; partially zeolitic; minor very small felsic phenocrysts; minor biotite, trace of clinopyroxene; cross-bedding.
Geologic Notes: Sample is from the upper tuff unit in the upper part of the Rocks of Pavits Springs.
Hydrogeologic Notes: Poor aquifer properties - very low porosity and permeability. Fine grain-size and zeolitization reduce aquifer properties.

Sample: 1197-Th-1-1 **Location:** N714800; E710300
Date Described: 11-4-96 **Geologist:** L. B. Prothro
Lithologic Description: **Reworked Tuff:** Light-olive-gray; vitric to weakly zeolitic; common to abundant felsic minerals of feldspar and quartz; rare to minor mafic minerals of biotite and hornblende, trace of clinopyroxene; rare lithic fragments less than 1 mm in size; moderately calcareous; granular fabric; medium-grained; poorly indurated.
Geologic Notes: Rocks of Winapi Wash. Sample is from a 2- to 3-ft-thick bed.
Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 1197-Th-1-2 **Location:** N714800; E710300
Date Described: 11-5-96 **Geologist:** L. B. Prothro
Lithologic Description: Limestone: Very-pale-orange to yellowish-gray; well to very well indurated; cryptocrystalline.
Geologic Notes: Rocks of Winapi Wash. Sample is from a 2- to 3-ft-thick bed.
Hydrogeologic Notes: Poor aquifer properties - very low porosity and permeability.

Sample: 1197-Th-1-3 **Location:** N714800; E710300
Date Described: 11-5-96 **Geologist:** L. B. Prothro
Lithologic Description: Limestone: Yellowish-gray; well indurated; finely crystalline; tuffaceous, with minor to common biotite.
Geologic Notes: Rocks of Winapi Wash. Sample is from a 2- to 3-ft-thick bed.
Hydrogeologic Notes: Poor aquifer properties - very low porosity and permeability.

Sample: 1197-Th-1-4 **Location:** N714800; E710300
Date Described: 11-5-96 **Geologist:** L. B. Prothro
Lithologic Description: Sandstone: Light-olive-gray; poorly indurated; tuffaceous; very-fine-grained; moderately sorted; angular to subangular; predominately felsic minerals of feldspar and quartz with lesser biotite and lithic fragments; very calcareous; calcite cement.
Geologic Notes: Rocks of Winapi Wash. Sample is from a 2- to 3-ft-thick bed.
Hydrogeologic Notes: Moderate aquifer properties - moderate porosity and permeability. Small grain-size and tuffaceous nature reduce aquifer properties.

Detailed Sample Descriptions (continued)

Sample: 1197-Th-2-1 **Location:** N714800; E698900
Date Described: 11-21-96 **Geologist:** L. B. Prothro
Lithologic Description: Limestone: Very pale orange; well indurated; cryptocrystalline; argillaceous.
Geologic Notes: Rocks of Winapi Wash. Sample is from a 2-ft-thick bed very near the contact with the Eureka Quartzite.
Hydrogeologic Notes: Poor aquifer properties. Low porosity and permeability.

Sample: 1197-Th-2-2 **Location:** N714800; E698900
Date Described: 11-21-96 **Geologist:** L. B. Prothro
Lithologic Description: Limestone: Moderate-yellowish-brown; well indurated; cryptocrystalline; fossiliferous with common gastropod fossils.
Geologic Notes: Rocks of Winapi Wash. Sample is from a 1- to 2-ft-thick bed above 1197-Th-1-1.
Hydrogeologic Notes: Poor aquifer properties. Low porosity and permeability.

Sample: 1197-Tpas-1-1 **Location:** N723950; E696800
Date Described: 11-7-96 **Geologist:** L. B. Prothro
Lithologic Description: Reworked Tuff: Yellowish-gray (5Y 7/2); vitric to slightly zeolitic; common felsic phenocrysts of quartz and feldspar; minor mafic minerals of hornblende and slightly less biotite; minor lithic fragments less than 0.5 mm in size; slight granular fabric; poorly to moderately indurated.
Geologic Notes: Rocks of Pavits Spring.
Hydrogeologic Notes: Good vitric-tuff aquifer - high porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 1197-Tpas-1-2 **Location:** N723950;
E696800

Date Described: 11-7-96 **Geologist:** L. B. Prothro

Lithologic Description: **Bedded Tuff:** Yellowish-gray (5Y 8/1); vitric; very pumiceous with very abundant pumice up to 1 cm in size; minor felsic phenocrysts of feldspar and quartz; rare to minor mafic minerals of hornblende and biotite; lithic fragments conspicuously absent; poorly indurated.

Geologic Notes: Rocks of Pavits Spring. Probably a pumice-rich ash-fall tuff.

Hydrogeologic Notes: Very good vitric-tuff aquifer - high porosity and permeability.

Sample: 1197-Tpas-1-3 **Location:** N723950;
E696800

Date Described: 11-7-96 **Geologist:** L. B. Prothro

Lithologic Description: **Sandstone:** Pale- to dark-yellowish-brown; poorly indurated; very tuffaceous, with fine- to medium-grained, angular to subangular, and moderately sorted feldspar and quartz, with lesser pumice, lithic fragments, biotite, and hornblende.

Geologic Notes: Rocks of Pavits Spring. Sample from a 0.5-ft-thick bed underlying and in contact with tuff unit of sample 1197-Tpas-1-4.

Hydrogeologic Notes: Very good aquifer - high porosity and permeability.

Sample: 1197-Tpas-1-4 **Location:** N723950;
E696800

Date Described: 11-7-96 **Geologist:** L. B. Prothro

Lithologic Description: **Bedded Tuff:** Medium-light-gray; vitric to partially zeolitic; rare to minor felsic phenocrysts of feldspar and quartz; minor mafic minerals of biotite and hornblende; rare lithic fragments up to 5 mm in size, increasing in size and abundance towards base; poorly indurated.

Geologic Notes: Rocks of Pavits Spring. Sample is from a 5- to 6-ft-thick bed.

Hydrogeologic Notes: Good vitric-tuff aquifer - high porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 1197-Tpas-2-1 **Location:** N724400;
E696600

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Nonwelded Tuff: Yellowish-gray (5Y 8/1); vitric to partially zeolitic; rare pumice; minor feldspar and quartz phenocrysts; rare biotite, trace clinopyroxene; trace lithic fragments; moderately calcareous.

Geologic Notes: Rocks of Pavits Spring. Thickness unknown but probably less than 5 ft.

Hydrogeologic Notes: Moderate to good vitric-tuff aquifer properties - moderate to good porosity and permeability.

Sample: 1197-Tpas-2-2 **Location:** N724400;
E696600

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Reworked Tuff: Pale-yellowish-brown; vitric to partially zeolitic; very abundant feldspar and quartz crystals; rare hornblende and lesser biotite; common lithic fragments; weakly calcareous; granular fabric; fine-grained; cross-bedded.

Geologic Notes: Rocks of Pavits Spring. Sample is from a 3-ft-thick bed approximately 10 feet above sample 1197-Tpas-2-1.

Hydrogeologic Notes: Moderate to good vitric-tuff aquifer properties - moderate to good porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 1197-Tpas-3-1 **Location:** N724950;
E697000

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Ash-Fall Tuff: Yellowish-gray (5Y 7/2); vitric; common white pumice; felsic phenocrysts conspicuously absent; rare biotite; very abundant clear glass shards; very fine-grained to silt-size.

Geologic Notes: Rocks of Pavits Spring.

Hydrogeologic Notes: Good vitric-tuff aquifer properties - high porosity and permeability.

Sample: 1197-Tpas-3-2 **Location:** N724950;
E697000

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Conglomerate: Yellowish-gray (5Y 7/2); well indurated; paraconglomeratic; 30 - 40% poorly sorted, subrounded to well rounded, clasts of mostly pre-Tertiary quartzite and lesser Tertiary volcanics up to 2 cm in size; minor felsic crystals; tuffaceous (partially zeolitic ash) matrix with trace biotite; calcareous; zeolite and calcite cement.

Geologic Notes: Rocks of Pavits Spring. Sample is from a 1- to 2-ft-thick bed.

Hydrogeologic Notes: Poor aquifer properties. Low porosity and permeability. Poor sorting and zeolitic and calcareous matrix reduce porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 1197-Tpat-1-1 **Location:** N716350; E698700

Date Described: 11-20-96 **Geologist:** L. B. Prothro

Lithologic Description: Water-laid Ash-Fall Tuff: Yellowish-gray (5Y 7/2); argillized/zeolitized; pumiceous with very abundant angular fragments of pumice; rare felsic phenocrysts; rare biotite; trace very small lithic fragments; granular fabric; medium-grained to coarse-grained.

Geologic Notes: Rocks of Pavits Spring. Sample from a 20-ft exposure. Exposed surfaces have a mud-cracked, frothy texture and appearance. Unit forms hummocky terrain.

Hydrogeologic Notes: Tuff confining unit properties. Although has high porosity and permeability, water poured on sample initially soaks up rapidly then clays(?) swell(?) and/or slake, significantly reducing porosity and permeability to the point where no more water is absorbed.

Sample: 1197-Tpat-1-2 **Location:** N716350; E698700

Date Described: 11-20-96 **Geologist:** L. B. Prothro

Lithologic Description: Sandstone: Dusky-yellowish-green; poorly indurated to friable; overall fine-grained, but ranges from silt and clay to very coarse-grained; very poorly sorted; subangular to subrounded; tuffaceous, consisting mainly of felsic minerals, lithic fragments, magnetite, and clay matrix; very argillaceous (sample swells and slakes when wet); moderately calcareous; clay and calcite cement; satin spar gypsum common.

Geologic Notes: Rocks of Pavits Spring. Sample from a 5- to 10-ft-thick exposure directly overlying unit of sample 1197-Tpat-1-1. Exposed surfaces have a mud-cracked, frothy texture and appearance. Unit forms hummocky terrain.

Hydrogeologic Notes: Confining unit properties. Although has high porosity and permeability, water poured on sample initially soaks up rapidly, then clays immediately swell and slake significantly reducing porosity and permeability to the point where no more water is absorbed.

Detailed Sample Descriptions (continued)

Sample: 1197-Tpat-1-3 **Location:** N716350; E698700

Date Described: 11-20-96 **Geologist:** L. B. Prothro

Lithologic Description: Sandstone: Olive-gray; poorly indurated; medium-grained becoming coarse-grained and conglomeratic near base; moderately sorted; subangular to subrounded; slightly tuffaceous, consisting mainly of felsic minerals, lithic fragments, magnetite, and clay matrix; very calcareous; common calcite cement.

Geologic Notes: Rocks of Pavits Spring. Sample is from a 1- to 2-ft-thick exposure within unit of sample 1197-Tpat-1-1.

Hydrogeologic Notes: Moderate aquifer properties - moderate porosity and permeability.

Sample: 1197-Tpat-2-1 **Location:** N716500; E698500

Date Described: 11-20-96 **Geologist:** L. B. Prothro

Lithologic Description: Reworked Lapilli Tuff: Light-brown (5YR 5/6); partially zeolitic; very abundant felsic phenocrysts of feldspar and lesser quartz, with some showing rounding; minor biotite; 50% subrounded to rounded lapilli up to 1.5 cm in size.

Geologic Notes: Rocks of Pavits Spring. Thickness unknown. Cross-bedding observed in outcrop.

Hydrogeologic Notes: Good aquifer properties - good porosity and permeability.

Detailed Sample Descriptions (continued)

Sample: 1197-Tpat-2-2 **Location:** N716500; E698500

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Sandstone: Grayish-black to grayish-orange; poorly to moderately indurated; medium- to coarse-grained; moderately sorted; angular to subangular; tuffaceous with feldspar and quartz crystals, biotite, and tuffaceous rock fragments; very abundant manganese oxides as matrix and thin layers up to 1 cm thick; calcareous; calcite cement.

Geologic Notes: Rocks of Pavits Spring. Thickness only 0.5 ft.

Hydrogeologic Notes: Moderate aquifer properties - moderate porosity and permeability.

Sample: 1197-Tpat-2-3 **Location:** N716500; E698500

Date Described: 11-21-96 **Geologist:** L. B. Prothro

Lithologic Description: Reworked Tuff: Moderate-brown (5YR 4/4); argillaceous and zeolitic; minor to common rounded pumice; minor to common quartz and feldspar phenocrysts; minor biotite; very rare lithic fragments; poorly indurated to friable.

Geologic Notes: Rocks of Pavits Spring. Thickness unknown. Exposed surfaces have a mud-cracked, frothy texture and appearance. Unit forms hummocky terrain.

Hydrogeologic Notes: Tuff confining unit - although has porosity and permeability, water poured on sample initially soaks up rapidly, then clays swell and/or slake significantly reducing porosity and permeability to the point where no more water is absorbed.

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