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A Feasibility Study of Water Production from Deep Carbonate Aquifers in Nevada

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A division of the University and Community College System of Nevada

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FOREWORD

The research reported on herein was conducted under a Letter of Agreement dated August 15, 1977, with the Las Vegas Valley Water District.

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CONTENTS

TABLES

FIGURES

ABSTRACT

Approximately the eastern one-third of the state of Nevada (40,400 mi^2) is underlain by thick sequences of carbonate rocks. Review of existing information and data pertaining to this area continues to support the hypothesis of widespread carbonate aquifers. Large regional interbasin groundwater flow systems are developed in these carbonate rocks and potentially contain large quantities of developable water. Caves, wildcat oil and gas wells, springs and mines have been used to evaluate permeability in the carbonate strata. Cambrian and Devonian age carbonate units probably contain more zones of high permeability. They bracket the lower carbonate aquifer hydrostratigraphic unit which is highly fractured and solutionally modified with measures of coefficients of transmissiblity ranging up to 1,000,000 gpd/ft. If the results of the investigation of Great Basin regional carbonate groundwater flow systems prove that large quantities of water are available and withdrawal of these waters would not significantly lower the water table and prior appropriators could be satisfied, then appropriation of these waters might be accomplished, provided the Nevada State Engineer was to determine that the withdrawal and beneficial use of this water was essential for the welfare of the area. A Phase II exploration plan has been divided into two major tasks. The first is to investigate the functioning of large regional carbonate flow systems in the Great Basin. Groundwater recharge, discharge and movement and aquifer properties will be investigated, along with relationships between the carbonate and alluvial aquifers. The second is designed to acquire new subsurface data through the use of petroleum wildcat and exploratory test holes. Locations of exploratory test holes are proposed for Las Vegas Valley, Indian Springs/Corn Creek, recharge areas, Kane Springs Valley and Long Valley.

INTRODUCTION

Carbonate rocks underlie approximately twenty percent of the land surface of the United States and generally contain large quantities of groundwater (McGuinness, 1963; Davies and LeGrand, 1972). Carbonate terrains have a large range in permeability including some of the most extensive and productive aquifers in the world (Herak and Stringfield, 1972). Many are proven excellent groundwater supplies, such as in Florida, Texas and throughout the Appalachian states (National Academy of Sciences, 1976).

As indicated in Figure 1, based on the distribution of bedrock exposure, approximately the eastern one-third of Nevada (40,400 mi^2) is underlain by carbonate rocks. Such rocks are known to contain large quantities of water under the Nevada Test Site (NTS) (Winograd and Thordarson, 1975). Based on background data reviewed for this report it is believed that the deep carbonate aquifer systems extend well beyond the area of existing hard data to include most of the carbonate rock province in Nevada.

Project Objectives

This report is the first phase of a new program of study of the water supply potential of deep carbonate aquifers in southern and eastern Nevada. It is part of a large research program better known as the "Deep Hole" project. Work on this phase has been supported by the Las Vegas Valley Water District for the period September 1977 to August 1978. This initial work was designed to assemble and interpret existing geologic, geophysical, hydrologic and geochemical information available in areas of Nevada believed potentially favorable for development of water supply from carbonate aquifers. The general objective was to determine promising areas for test drilling to substantiate the belief in widespread existence of deep carbonate aquifers.

Specific project objectives were five-fold, as noted below:

1. Compile and interpret existing hydrologic, geologic, geochemical and geophysical data bearing on carbonate groundwater flow systems in eastern and southern Nevada, with emphasis on the deep system in Clark County and environs.

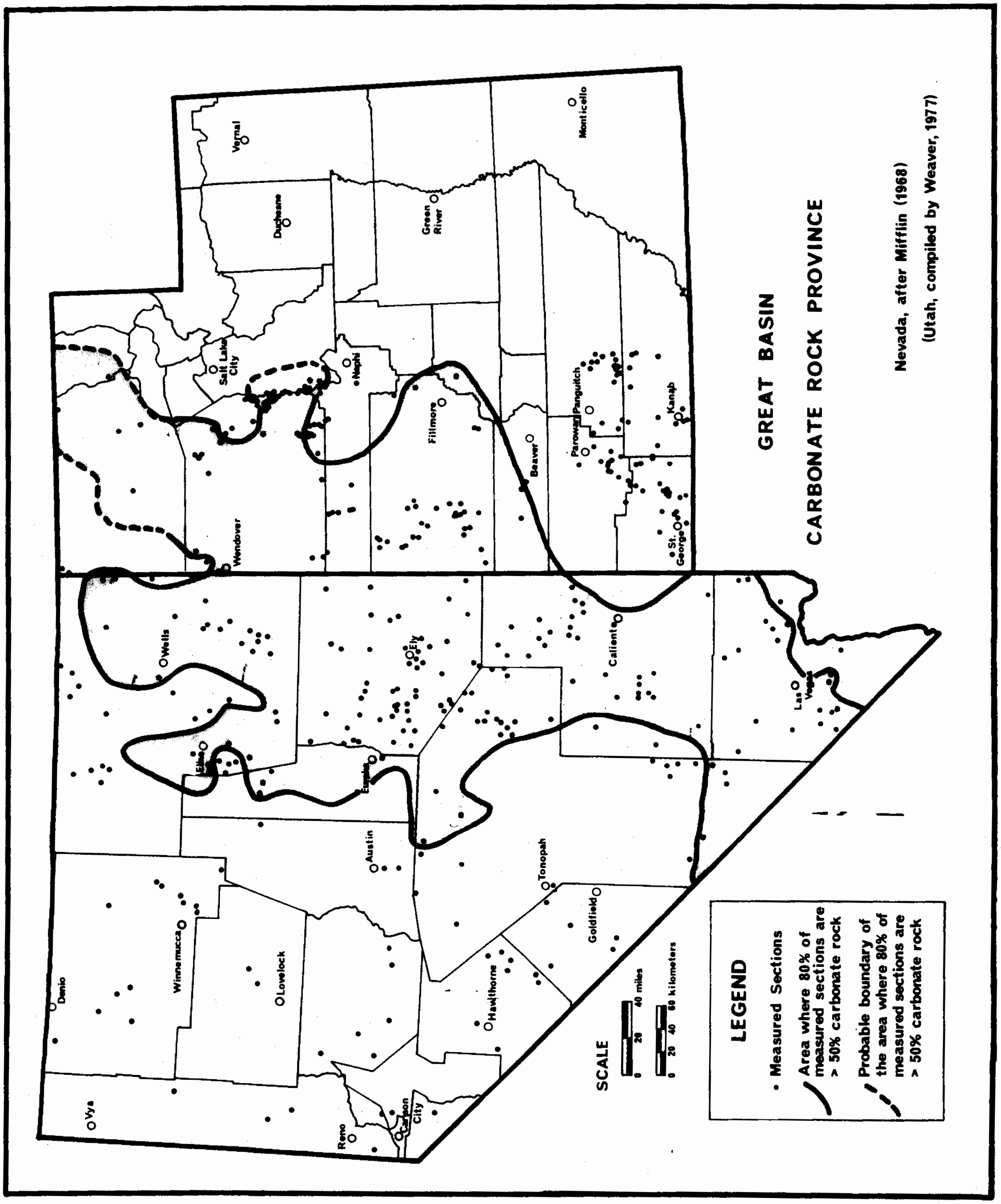


Figure 1. Great Basin Carbonate Rock Province

2. Review potential water management implications in terms of existing Nevada water law and implementation.
3. Develop a comprehensive report that incorporates all available information.
4. Using above information, produce a detailed exploration plan and research program for future work as follows:
   a. Develop maps indicating areas of most favorable locations for test and exploration wells.
   b. Determine exploration and test drilling program, including projected depths, drilling conditions and tests to be conducted.
5. Develop proposal(s) for subsequent phases of exploration drilling.

Background

The limited surface water of Nevada has been extensively developed and many of the alluvial groundwater basins are used to the point of estimated perennial yield, thus are closed to further development. As a consequence, a large part of the traditional water resource is no longer available and new uses can only be realized through transfer of water rights from existing uses. In fact, southern Nevada has reached the point in water supply planning that recognizes no proven additional supplies to meet trends in demand beyond about the year 2000. The deep carbonate rocks of southern and eastern Nevada may represent a potentially "new" source of water. The magnitude of this source may be on the order of thousands of acre-feet per year. Little is presently known about this resource in terms of the dynamics of recharge, discharge and physical aquifer characteristics, its total extent or where it could be developed at a reasonable cost and without interfering with existing ground or surface water development.

Carbonate rock aquifers are the least understood and exploited type of aquifers for their extent in the Great Basin. As indicated above, approximately the eastern one-third of the State of Nevada is underlain by carbonate rocks. Over long periods of time, these rocks have been made permeable in localized zones through the solution of carbonate minerals by percolating water. Most of the highest yield water wells known are constructed in such permeable zones of carbonate rocks in many parts of the world.

There is abundant evidence in Nevada that water does indeed flow in such zones, at least locally, in many areas of the region underlain by such rocks (Maxey and

Mifflin, 1966; Mifflin, 1968; Winograd and Pearson, 1976). The many wells drilled into carbonate rocks at the Nevada Test Site in southeastern Nye County amply demonstrate local occurrence of such deep aquifers (Winograd and Thordarson, 1975). Another type of evidence is the occurrence of many large springs associated with these rocks (see Plate III). Unbalanced water budgets in large areas of Nevada indicate important flow through carbonate rocks (Nevada Hydrologic Atlas, 1972; Mifflin, 1968). Large interbasin groundwater flow systems exist in much of this region within the carbonate rocks (Eakin, 1966; Mifflin, 1968; Naff, et al, 1974). Many of the intermountain basin alluvial aquifers are probably in some way related to these larger carbonate flow systems (Bateman, et al, 1972 and 1974).

History

The Great Basin region is characterized by its internal drainage and general aridity. There are few major rivers and streams and thus groundwater has been a key element in water supply. This reliance on groundwater naturally led to major concern about its origins, occurrence and sustained developable volumes. Over the years the general physiography, geological structure and lithology have exercised considerable influence on where and how the groundwater has been developed, on estimates of how much groundwater is available, and on how groundwater flows within the system.

Basically the structural framework of the region can be characterized as a series of north-south trending mountain ranges with general lithology ranging from carbonate rock sequences to volcanic and granitic rocks. These rock types also underlie the valleys at depths ranging from several hundreds to several thousands of feet. The valleys are filled from their floors down to bedrock with unconsolidated alluvium and lake sediments, and in some basins semiconsolidated Tertiary sediments. The upper levels of the valley fill, consisting of layers of sands, gravels, silts and clays, have traditionally been considered as the "groundwater basin". Attention has been focused on these alluvial basins for estimating groundwater availability and developing water supplies.

During the early 1950's the Nevada District Office of the U.S. Geological Survey, in a cooperative program with the Nevada Department of Conservation and Natural Resources, developed a technique for estimating the average annual natural recharge to these valley fill groundwater basins. The cooperative program became a concerted effort to develop water supply estimates for each basin during the 1960's and 1970's. The estimating technique used was basically that of developing a valley water budget wherein total natural inflow to each valley must equal total outflow plus changes in storage. In many valleys it was found impossible to balance these water budgets because there was either too much or not enough discharge, and the differences were significantly larger than the probable errors in inflow estimates. These observations and renewed interest in flow system theory led to the studies by personnel at Desert Research Institute (DRI) (Maxey and Mifflin, 1966; Mifflin, 1968) and the U.S. Geological Survey (USGS) (Eakin, 1966) into the reasons for these imbalances. The general conclusions were that while the valleys are topographically separated, there are instances where there is significant groundwater flow between the valleys beneath the mountain ranges. These interbasin groundwater flows (regional flow systems) were found to occur primarily in that portion of Nevada where a significant portion of the geologic section consists of carbonate rock lithologies (Mifflin, 1968; Nevada Hydrologic Atlas, 1972). Supporting evidence for the regional flow systems concept was found in the valley water budgets, the occurrence of major springs issuing from or near carbonate rocks, regional valley fill aquifer water levels and regional groundwater chemistry (Naff, 1973).

The regional groundwater flow system concept was generally accepted by the mid- to late 1960's. However early in the development of the concept there was little evidence on depths at which these flow systems existed, the effective permeability and porosity of the hydrostratigraphic units or whether these "aquifers" were economically developable. The early direct evidence concerning these latter unknowns came about as a result of the 1963 Limited Test Ban Treaty, which called for all nuclear testing to be done underground. An early concern with such testing was the possibility of radioactive contamination of groundwater. The presence of groundwater was also a possible factor in the successful containment of subsurface detonations. As a result, the U.S. Atomic Energy Commission (now U.S. Department of Energy, DOE) contracted with USGS, DRI, and other research groups to evaluate hydrologic factors associated with this testing. As part of such hydrologic programs numerous hydrologic test holes were drilled in the vicinity of the Nevada Test Site (NTS) and the Central Nevada Test Area in Hot Creek Valley. These test holes penetrated the valley fill and entered the underlying volcanic and carbonate rocks to significant depths. Some holes were as much as 8000 feet deep and encountered significant permeability and large volumes of water in the carbonate rocks. These provided the first direct hydrogeologic documentation that groundwater moved through the deep-lying carbonate rocks under the NTS to other closed basins (Winograd, 1962). At the NTS, hydrologic test hole, nuclear event observation hole and event emplacement hole data indicate that as much as 235 million acre-feet of groundwater may be stored and slowly moving through the carbonate rocks (data from Winograd and Thordarson, 1975). This quantity of water under the NTS would be enough, for example, to provide all of Nevada's need for approximately 40 years at the present rate of consumption. However, location of this water, probable cost of development for use in other areas of Nevada, and many other considerations suggest a search for similar and possibly more attractive deep carbonate rock aquifers for future development.

As with all research, funding of carbonate aquifer studies has proved to be the biggest problem, apart from actually achieving sometimes difficult research objectives. From the early 1970's until his untimely death in early 1977, Dr. George B. Maxey and others, armed with the available information, worked to obtain funding for what was to be called the "Deep Hole" project. Research objectives were clarified, proposals developed, and funds were diligently sought to begin the program of research believed necessary to evaluate this "new" water resource alternative for the State.

In August, 1977, the Las Vegas Valley Water District Board of Directors made it possible to begin initial "Deep Hole" work with money to support the first phase of the research, as reported herein. The questions of where to drill, and how much exploratory drilling would be necessary before production wells could be developed were primary. Another important question was whether or not such groundwater can be considered and managed as a "separate" water resource, that is, as water so far removed from the conventionally developed groundwater in the alluvial basins that it can be developed and managed on a different basis.

An adequate research program which involves actual drilling and aquifer testing to address the most important questions is estimated to cost about ten million dollars over a number of years. This, or some part of this, will be Phase II of the

"Deep Hole" research program. The high price tag is due mostly to the very costly drilling that is similar to petroleum exploration, using large drilling rigs and constructing test holes that could range up to 10,000 feet in depth. Research drilling costs are probably many times more costly than possible future production well drilling costs due to hydrologic testing that is desirable and necessary when each permeable zone is penetrated. This is coupled with the need to penetrate to much greater depths to more fully explore and understand the flow systems that may eventually be developed. The previously discussed questions of relations of deep carbonate aquifers to conventionally used groundwater resources demand carefully developed data that do not exist at the present time.

The test drilling phase of the research program is believed justified because of the potential economic impact on Nevada's future if the deep carbonate aquifers can be used. In our present state of knowledge, it has yet to be demonstrated that such aquifers could be developed for large scale water supply purposes and, if so, what the cost of the water would be. If, for example, the economics of developing deep aquifers for water supply is less costly than importing water or reclaiming waste water, this could have tremendous impact on Nevada's future development. Over one-third of Nevada is underlain by these carbonate rocks, and most of the surface water and conventional groundwater is already in use. Generally, localized water supplies sufficient to permit major new developments are unavailable without eliminating much of the present water uses. In some basins, there are essentially no conventional water supplies.

In the Las Vegas area, there is no proven additional source of new water supply once Nevada's share of the Colorado River is fully utilized, a condition that may be reached within 20 to 25 years. At that time any growth will need to be based on water conservation, intensified mining of conventional groundwater, and/or imported groundwater from other valleys at the expense of existing water uses in those valleys. This has been the planning picture to present, without recognition of the potential alternative represented by the deep carbonate aquifers. In view of these realities in southern Nevada, the incentive is becoming sufficiently strong to explore and evaluate the carbonate aquifer alternative regardless of the high costs for test drilling.

HYDROGEOLOGY

The hydrogeologic setting provides the boundary conditions determining the flow characteristics of an aquifer. Such geologic parameters as stratigraphy, lithology and structure are important in determining the type of aquifer, location of recharge and discharge areas and the nature of the porosity and permeability of the aquifer.

An overview of the hydrogeology of carbonate aquifers is presented by Stringfield and LeGrand (1969). White (1969, 1977) discusses the effects of structural and stratigraphic controls on carbonate aquifer systems of low to moderate relief. The hydrogeology of carbonate aquifers in folded and faulted rocks is discussed in Parizek, et. al. (1971).

Various aspects of eastern Nevada geology, hydrogeology and hydrology have been discussed by many authors. The bibliography at the end of this report contains over 500 entries and is a compilation of the many references which contain information of potential utility.

Physiography

The study area (Figure 1) generally lies in eastern and southern Nevada east of longitude 117^{o}. It encompasses approximately 40,400 mi^2 of Clark, Elko, Lincoln, Nye and White Pine counties. This area is within the central Great Basin section of the Basin and Range physiographic province. The area is characterized by isolated, elongate, subparallel block-faulted mountain ranges and broad intervening, nearly flat floored alluvial valleys or basins. The mountains tend to run north or northeast with many rather regularly spaced between 15 and 25 miles apart. They are 20 to 100 miles long, 5 to 15 miles wide and many have elevations between 8,000 and 10,000 feet above mean sea level (msl). Wheeler Peak on the Nevada-Utah border is the highest point totally within Nevada at 13,063 feet msl. Mt. Charleston in the Spring Mountains is among the highest peaks in the state at 11,918 feet. The basins are filled with varying thicknesses of alluvium derived from the surrounding mountains. Basin sediment thicknesses range from a few hundred feet to greater than 10,000 feet. Valley floor elevations range from approximately 2,000 feet msl in Las Vegas Valley to about 7,000 feet msl in the central part of the area.

Climate

The local climates of the region are extremely variable, depending primarily upon the altitude. The valleys are arid to semi-arid, characterized by low precipitation and humidity and extreme diurnal variation in temperature. The mountains are semi-arid to sub-humid, receiving about one-half of their precipitation as snow during the winter. Thunderstorms account for much of the summer precipitation. Annual precipitation is quite variable, with mean annual precipitation rangeing from as little as 3 inches in some of the southern valleys to more than 30 inches in the highest mountain ranges. The majority of the basin and foothills areas receive 5 to 12 inches.

Stratigraphy

Eastern Nevada is stratigraphically complex. It lies within the miogeosynclinal belt of the Cordilleran geosyncline, in which 30,000 to 40,000 feet of marine sediments accumulated during the Precambrian and Paleozoic eras (Stewart, 1964; Roberts, 1964). Plate I is the Million-Scale Geologic Map of Nevada (Map 57) published by the Nevada Bureau of Mines and Geology (NBMG, 1977). It indicates general groupings of rocks. Those of most interest to this study are:

1. Precambrian and lower Paleozic Carbonate and Transitional Assemblages indicated on the map in light purple (PzZc). They are rocks of the miogeosynclinal belt of the Cordilleran geosyncline. The carbonate assemblage consists of limestone, dolomite and minor amounts of shale, siltstone, sandstone and quartzite.
2. Upper Paleozoic Carbonate and Siliceous Detrital Rocks are indicated on the map in light blue (uPzc). They include thin sequences of conglomerate, siltstone and limestone within the Antler Orogenic Belt; relatively thick sequences of shale, siltstone, sandstone conglomerate, sandy limestone and limestone along the eastern margin of the Antler Orogenic Belt or in the foreland basin to east; and moderately thin to thick sequences of carbonate rock in the foreland basin or on the shelf.

Plate II is a correlation chart of eastern Nevada stratigraphic units modified from NBMG Bulletin 72 (1973). The latter contains references to described sections. Detailed descriptions of the various Paleozoic stratigraphic units of interest to this study are given in Appendix I and are derived from many sources (see Bibliography).

Generally speaking, marked facies changes and structural displacements make it extremely difficult to predict lithologic characteristics beyond local areas of exposures in the mountainous areas. Even though names for formations are frequently carried from one study area to another, very often thickness, lithologic character, and presumably associated hydrogeologic characteristics may differ in the extreme. Unfortunately, the literature review clearly demonstrates a pervasive omission in nearly all pre-existing geological studies with respect to hydrogeologic characteristics of the carbonate rock formations in Nevada. Rarely is there consistent mention or description of fracture or solution characteristics, or even relative differences between studied formations. The majority of detailed geologic mapping and formation description has been directed at determining age relationships, lithology, distribution, and structural characteristics. Some of the limited number of references encountered that give attention to hydrogeologic aspects of carbonate rocks in Nevada are Maxey and Jameson (1948), Winograd (1962), Naff et. al. (1974), Winograd and Thordarson (1975), Mifflin (1968), McLane (1972, 1974) and Dudley (1967).

Therefore, the conclusion of this part of the study is that the conventional geologic literature available sheds little light on potential target horizons with exceptional high permeability. Rather, these studies will become more useful as site specific information is acquired in test drilling and more hydrologic data from specific formations is developed.

Structure

Eastern Nevada is characterized by extremely complex geologic structures as a result of superposition, one upon the other, of several periods and types of deformation. Probably three periods of deformation have affected the carbonate rock sequences within the region of interest. In some areas Permian-Triassic deformation seems probable, and some metamophism and igneous intrusions are associated. Folding and thrust faulting of the late Precambrian and Paleozoic rocks occurred during the late Mesozoic-early Tertiary Laramide orogeny. Normal block faulting, which produced the present day basin and range topography, started in the Oligocene and reached a maximum in the Miocene, with some activity extending to the present time. Strike-slip faults and shear zones have been active during the Laramide and block faulting tectonic periods. Movement along the Roberts Mountain Thrust was as much as 90 miles

(Wallace, 1964). Displacments of from 25 to 40 miles have been mapped along the Las Vegas Valley shear zone, in Death Valley, the Amargosa Desert, the NTS and in Las Vegas Valley.

Structural history relates to at least four important areas of consideration in the study of deep carbonate aquifers for water supplies. The first and most fundamental is the distribution of the carbonate rocks in the subsurface. The history of faulting, folding and erosion controls the basic distribution of the rock types of interest. In much of the region of interest knowledge of this distribution is more or less restricted to bedrock exposures due to the extremely complicated history of deformation, as demonstrated by the areas mapped in detail. Presence of many low and high angle thrust faults, associated folding, and superimposed normal faulting greatly complicates the prediction of distribution of formations in the subsurface, particularly in the basin areas. Until demonstrated otherwise, the complicated structural relationships displayed in outcrop areas of the mountains are assumed to persist in the basement rocks underlying the alluvial basins. Changes in structure from range to range is often the case, and therefore interpretation of structure hidden under the basins between the ranges is generally difficult. Locations for test drilling, particularly in areas of marked structural changes in short distances, seem best where basin margin structure is exposed and initial stratigraphic and structural control in the upper part of a test hole is less subject to change.

Secondly, structural development has rearranged rocks to the extent that permeable and impermeable lithologies are often juxtaposed. This can in turn create corridors of permeability in any given direction and generate relatively impermeable boundaries on a localized and, perhaps, regional scale. Considered in terms of flow system configuration and size, this aspect has special significance. It is well demonstrated on a local basis that faults and stratigraphic control on permeability can determine general patterns of groundwater flow. What is less evident in documented cases is the possible control structure may have in the configuration of large, regional flow systems. Further, major linear fault zones, such as regional shear zones and the range front fault zones that sometimes extend for great distances must have, in at least some areas, very profound influence on the movement of groundwater. Little firm evidence exists in the literature as to the importance of such zones throughout the carbonate rock province.

The third aspect of structural history of considerable importance is the direct impact on permeability. Most carbonate rocks deformed at shallow depths within the crust behave in a brittle manner, and thus shear and fracture during deformation. Concentration and extent of fractured carbonate rocks is important in the degree of development of secondary and tertiary permeability, as discussed later. Fracturing of relatively youthful age in a geologic sense is believed most important with respect to permeability, as fractures in carbonate rocks may reheal over prolonged periods of time due to recrystallization of carbonate minerals.

The fourth aspect of structural history perhaps controlling permeability in the carbonate rocks relates to present and past patterns of groundwater flow due to position in past circulation systems of groundwater. From at least Miocene time, and perhaps the early Tertiary, the relative positions of carbonate rocks in the Basin and Range Province have been changing with respect to recharge areas, discharge areas, and normal flow paths of groundwater. Depending on the relative position at any given time, the potential amount of solution in a fractured carbonate rock may vary greatly due to the thermodynamic environment and associated flux of groundwater.

This type of structural history may have important influences over the distribution of permeability in the subsurface. In some parts of Nevada there is considerable evidence that Basin and Range configuration may not have been constant since the block faulting became a dominant pattern of deformation. Some carbonate rocks now lying buried beneath basin fill deposits may not always have occupied such structural and hydrogeologic environments. Conversely, other zones of carbonate rocks may have maintained their relative positions with respect to antecedant groundwater circulation patterns.

Hydrologic Significance of Geologic Setting

Permeability

This basic parameter of rock, combined with total cross sectional area and hydraulic gradient, determines the rate of flow and location of possible flow paths. Carbonate rock permeability is of three types: (1) primary porosity and permeability due to the presence of the initial communicating pore spaces; (2) permeability due to a network of joints, fractures, and bedding planes; and (3) permeability due to cavernous or solution openings. A carbonate aquifer can have a large tertiary permeability due to solutional development of an extensive system of interconnected cave conduits ranging in cross sectional area from hundredth of a square inch to hundreds of square feet.

Structural Controls

Regional movement of groundwater may be strongly influenced by the late Mesozoic-early Tertiary deformation of the late Precambrian and Paleozoic miogeosynclinal rocks, their subsequent erosion, and the faulting that took place during the late Cenozoic Orogeny.

An example of this influence in southern Nevada is reported in Naff, et al. (1974). They state that deformation of the Tertiary rocks is highly variable. Simple tilting and block faulting occurs in Las Vegas, Pahrump, and Indian Springs Valleys, but in the Amargosa Desert complex folding and faulting in the Tertiary strata influence the quality and movement of groundwater.

Overthrust faults are abundant tectonic features in the region, but their impact on groundwater occurrence and movement at depth is little understood. Even the configuration of such faults is in question at depth. Burchfiel (1964) and Secor (1962) maintain that such faults are decollement structures which flatten out with depth from initial dips of 35^{o} to 50^{o}. In contrast, Vincelette (1964) and Fleck (1970) present evidence that a steep dip is also present at depth. If so, such faults may form elongated corridors of carbonate rocks that extend to considerable depth.

Thousand of normal faults, commonly with displacements of less than 500 feet, but occasionally with displacements in the thousands of feet, are present in the region. In the Amargosa Desert, a north-south trending normal fault or fault zone in the Paleozoic carbonate rocks is believed to be responsible for the locus of springs in the Ash Meadows area (Winograd, 1971).

Structural control on several scales of consideration may well prove to be important in the search for aquifers in the carbonate rocks. The configuration of groundwater flow systems, particularly the large regional systems as later discussed and delineated in Plate III, seem to be at least partly controlled by structure. The structural grain of eastern Nevada is essentially north-south, and so are the generally apparent dominant flow directions of the very large interbasin groundwater systems.

Beginning as far north as Jakes Valley, regional flow trends in southerly directions in response to both linear grain of the geologic structure and to a lessor degree, gradually lower intermountain basins. Accurately defining flow paths is of great importance in terms of recognizing potential interference of carbonate aquifer development on existing alluvial groundwater basin development. If the postulated patterns of flow are essentially correct, there seems little question that areas could be located for development of water supplies well beyond the range of potential impact on existing uses connected to the same system.

The search for productive carbonate aquifers at reasonable depths in terms of production well fields with the need for limited exploration drilling is another basic aspect of structural control on permeability distribution. Based on the experience in other regions of carbonate rocks where wells located on fracture traces can be proven to be consistently better producers than randomly located wells (Lattman and Parizek, 1964, Siddiqui and Parizek, 1971), it seems reasonable to consider the normal faults and fault zones associated with the block faulting. The age of latest movements and the usual series of faults bounding the flanks of ranges well into the basinward depositional environments suggest enhanced opportunity for permeable zones. Further, in such positions fluid potential might be more favorable for production lifts, and the zones of penetrated rocks at shallow and intermediate depths should be areas of active circulation.

Hydrostratigraphy

Naff, et. al. (1974) and Winograd and Thordarson (1975) have considered the hydrostratigraphy of southern Nevada in the vicinity of the NTS. Table 1, modified from Winograd and Thordarson (1975), summarizes the Paleozoic stratigraphic and hydrologic units present.

The lower carbonate aquifer comprises the carbonate rocks of Middle Cambrian through Devonian age. It is the hydrostratigraphic unit of most interest to this study, as is demonstrated later in this report. In the area of the NTS these carbonate strata aggregate about 15,000 feet of thickness. The strata are complexly fractured, with permeability locally enhanced by solutional processes.

The transferability of the findings in the NTS area are somewhat questionable when applied to the rest of the carbonate province of Nevada. However, the experience gained in NTS studies is the only concentrated subsurface information, and provides

TABLE 1

Stratigraphic and Hydrogeologic Units at Nevada Test Site and Vicinity

(Modified from Winograd and Thordarson, 1975)

System	Series	Stratigraphic unit	Major lithology	Maximum thickness (feet)	Hydrogeologic unit	Water-bearing characteristics and extent of saturation[1]
Cretaceous to Permian		Granitic stocks	Granodiorite and quartz monzonite in stocks, dikes, and sills.	-	(A minor aquitard)	Complexly fractured but nearly impermeable.
Permian and Pennsylvanian		Tippipah Limestone	Limestone.	3,600	Upper carbonate aquifer	Complexly fractured aquifer; coefficient of transmissibility estimated in range from 1,000 to 100,000 gpd per ft; intercrystalline porosity and permeability negligible; saturated only beneath western one-third of Yucca Flat.
Mississippian and Devonian		Eleana Formation	Argillite, quartzite, conglomerate, conglomerite, limestone.	7,900	Upper clastic aquitard	Complexly fractured but nearly impermeable; coefficient of transmissibility estimated less than 500 gpd per ft; interstitial permeability negligible but owing to poor hydraulic connection of fractures probably controls ground-water movement; saturated only beneath western Yucca Flat and Jackass Flats.
Devonian	Upper	Devils Gate Limestone	Limestone, dolomite, minor quartzite.	>1,380	Lower carbonate aquifer	Complexly fractured aquifer which supplies major springs throughout eastern Nevada; coefficient of transmissibility ranges from 1,000 to 1,000,000 gpd per ft; intercrystalline porosity and permeability negligible; solution caverns are present locally but regional ground-water movement is controlled by fracture transmissibility; saturated beneath much of study area.
	? Middle	Nevada Formation	Dolomite.	>1,525		
Devonian and Silurian		Undifferentiated	Dolomite.	1,415		
Ordovician	Upper	Ely Springs Dolomite	Dolomite.	305		
	Middle	Eureka Quartzite	Quartzite, minor limestone.	340		
	?	Pogonip Group: Antelope Valley Limestone	Limestone and silty limestone.	1,530		
	Lower	Pogonip Group: Ninemile Formation	Claystone and limestone, interbedded.	335		
		Pogonip Group: Goodwin Limestone	Limestone.	>900		
Cambrian	Upper	Nopah Formation Smoky Member	Dolomite, limestone.	1,070		
		Halfpint Member	Limestone, dolomite, silty limestone.	715		
		Dunderberg Shale Member	Shale, minor limestone.	225		
	Middle	Bonanza King Formation Banded Mountain Member	Limestone, dolomite, minor siltstone.	2,440		
		Papoose Lake Member	Limestone, dolomite, minor siltstone.	2,160		
		Carrara Formation	Siltstone, limestone, interbedded. Upper 1,050 feet predominantly limestone; lower 950 feet predominantly siltstone.	1,050		
				950	Lower clastic aquitard[3]	Complexly fractured but nearly impermeable; supplies no major springs; coefficient of transmissibility less than 1,000 gpd per ft; interstitial porosity and permeability is negligible, but probably controls regional ground-water movement owing to poor hydraulic connection of fractures; saturated beneath most of study area.
	Lower	Zabriskie Quartzite	Quartzite.	220		
		Wood Canyon Formation	Quartzite, siltstone, shale, minor dolomite.	2,285		
Precambrian		Stirling Quartzite	Quartzite, siltstone.	3,400		
		Johnnie Formation	Quartzite, sandstone, siltstone, minor limestone and dolomite.	3,200		

the best picture of what should be expected in other areas and, perhaps with other thick sequences of carbonate rock in the saturated zone. Ranges of small to large transmissivities for any given hydrostratigraphic zone parallel somewhat the experience in other regions of carbonate rock aquifers. Frequently, there is recognized some systematic reason for variations in transmissivity, such as structural control (faulting, fracturing) or relative position in the flow system (concentrated flow in discharge areas, history of flow system position). For these reasons, location of test drilling should be based, at least in part, on selected environments where fracturing and a history of active groundwater could be anticipated in the effort to penetrate the zones of higher transmissivity.

One important aspect that warrants some discussion is the difference between most production wells in commonly developed aquifers and the search for carbonate aquifers in Nevada. Aquifers commonly developed are rarely more than several hundred feet in thickness. Usually, only a part of the so-called aquifer is highly permeable, and therefore most normal production wells receive a majority of water from a rather small total thickness of permeable earth materials. In Nevada, the marked thickness of the carbonate rock formations should greatly enhance the opportunity for penetrating a few highly permeable zones if several thousand feet of carbonate rock are penetrated. This is one of the important questions with respect to exploratory drilling for production wells. It seems reasonable to expect that several thousand feet of penetrated carbonate rock will generally yield sufficient water for a production well. If this proves to be the case, the costs for actual development of groundwater from carbonate rocks may prove economically competitive with some of the higher cost water now being used in southern Nevada.

It seems important also to point out that carbonate rocks are generally not permeable if no secondary or tertiary permeability exists. However, the history of deformation in Nevada is highly favorable for extensive fracturing and, presumably, some solution along existing fractures. For the amount of well-exposed carbonate rock that exists in the carbonate rock province of Nevada, there is not an abundance of known caves. There are , however, numerous small scale solution features associated with carbonate rock formations exposed at land surface. There are very little data in the literature documenting the frequency of solution features with respect to any particular carbonate rock formation.

FLOW SYSTEMS

Studies such as Eakin (1966), Maxey and Mifflin (1966), Mifflin (1968) and Winograd and Thordarson (1975) have established some of the fundamental concepts concerning groundwater flow systems in Nevada. Direct data on these systems are extremely sparse, and the details of the flow systems are not generally known. For purposes of this report, groundwater flow systems are defined as follows:

A. A "regional groundwater flow system" is loosely defined as a large groundwater flow system which encompasses one or more topographic basins. A regional system may include within its boundaries several groundwater basins; interbasin flow is common and important with respect to total volume of water transferred within the system boundaries; lengths of flow paths are relatively great when compared to lengths of flow paths of "local" groundwater flow systems.

B. A "local groundwater flow system" is generally confined to one topographic or groundwater basin; interbasin flow is not important with respect to total volume of water transferred within the system; the majority of flux of water within the system discharges within the associated groundwater basin; flow paths are relatively short when compared to regional systems.

General Approach

A groundwater flow system is a region within saturated earth materials where there is dynamic movement of groundwater from a recharge area to a discharge area. Water enters the system in the recharge area by virtue of passing from the land surface through the vadose zone to the zone of saturation. At the discharge area of the flow system, water passes from the saturated zone to positions outside the saturated zone of earth materials-the atmosphere, surface water drainage systems, lakes, capillary fringes in the vadose zone, plants and ice.

At every point within the flow system each molecule of water has the potential to move from the system; in other words, each water molecule within the flow system is moving, however slowly, toward the sink of the system. From a practical point of view, water which does not move, or moves so slowly as to be undetectable by virtue of fluid potential differences with respect to surrounding water, can be considered exterior to the dynamic flow system and such water is considered to be stagnant.

The ideal delineation of a groundwater flow system includes locating the recharge area and discharge area of the system, and reliably linking these parts of the system together by establishing a potential gradient from the recharge area to the discharge area. Further, ideal delineation should establish the boundaries between adjacent flow systems and other characterizing information such as depth of circulation, character of water at various positions in the system, and any other information about the flow system that may be useful. Ideal flow system delineation constitutes knowledge of flow paths of water in earth materials.

Reliable flow system delineation is made extremely difficult in many areas of Nevada by the lack of fluid-potential information, as well as the difficulties associated with attempts at locating and correlating recharge with discharge areas. Areas of recharge cannot be directly proven in many parts of Nevada. Further, most flow system boundaries in Nevada occur in mountainous terranes that are usually void of widespread subsurface information. Even in the basin and foothill areas, subsurface information is extremely localized, and fluid potential data are generally unavailable below the upper few hundred feet of saturation.

The basic approach by Mifflin (1968) was to use fluid potential information where available, either on the basis of water levels as indicated by wells or mines or by considering surface features closely related to groundwater, such as springs, seeps, base flow in perennial or live streams, phreatophytes and moist or salty areas associated with capillary fringes. Where this type of information is very sparse or ambiguous with respect to true saturation and associated fluid potential, more indirect evidence was called upon, such as hydrogeology, water budget relationships and availability of moisture for recharge. However, uncertainties remain in some areas even with these data. Studies of groundwater chemistry, groundwater temperature and detailed spring studies in carbonate rock terrane were made in an effort to supplement the more conventional data. Mifflin (1968) contains a detailed discussion of the concepts of groundwater potential.

Flow Systems As Depicted By Models

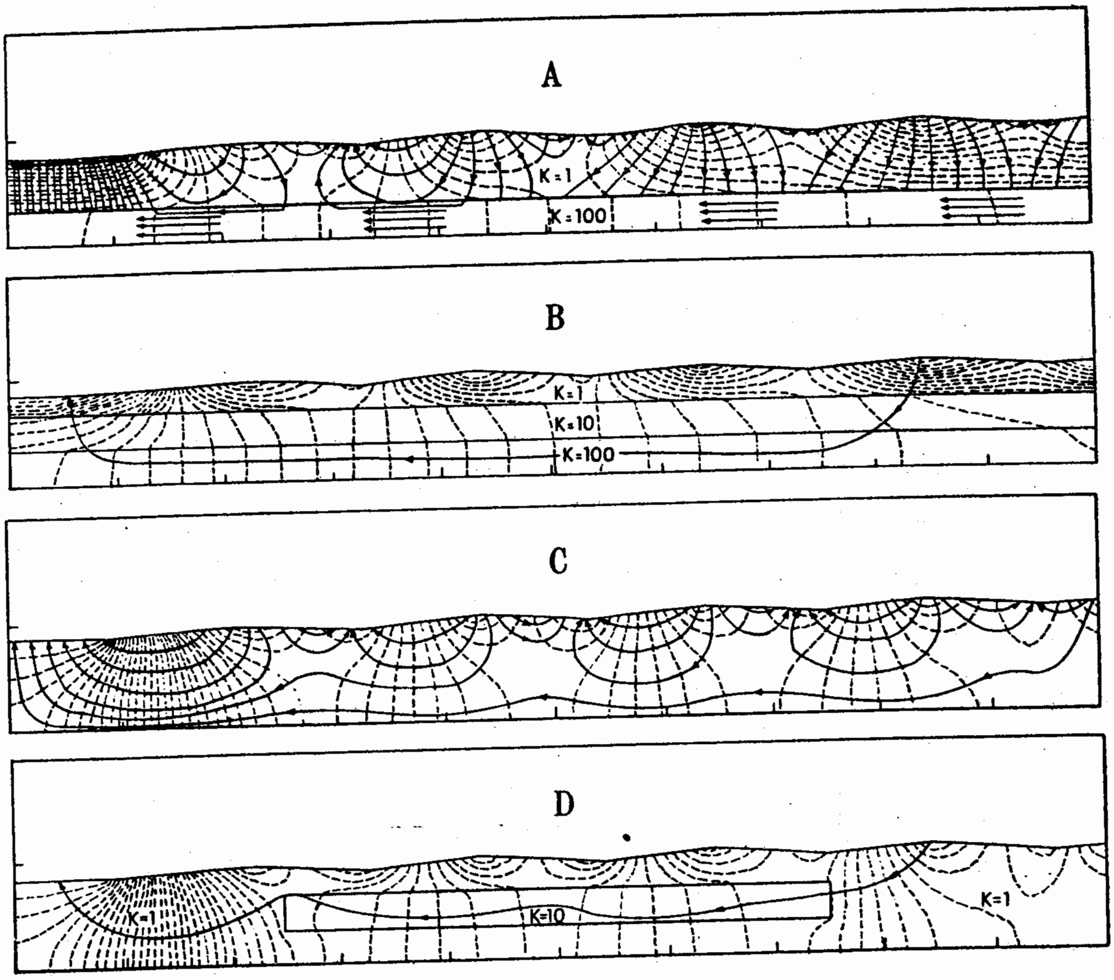
Previous investigations (Toth, 1962 and 1963; Freeze and Witherspoon, 1966 and 1967) have examined theoretical aspects of groundwater flow systems and modeled hypothetical systems in two dimensions. It has been found that, given certain boundary conditions, usually imposed by permeability, topography and available recharge, it is possible for what have been called local, intermediate and regionals systems to exist (Toth, 1963).

The models provide important points of departure in attempts to delineate naturally occurring groundwater flow systems. The importance of models can be seen in Figure 2, because a commonly assumed criterion for a system boundary is a region of high groundwater potential. These regions of high potential are usually recognized in nature by the configuration of saturation, and fluid potentials at depth are rarely known. The models in Figure 2 clearly suggest that such regions of high fluid potentials are not necessarily perfect boundaries to the system as a whole, and that flow can occur at depth from one "cell" of the depicted system to another.

Most important to the flow-system delineation are hydrogeologic conditions of relatively high permeability at depth such as exists in carbonate rocks. In such situations models suggest that large quantities of water can move from one "cell" to another. Thus, it may be insufficient to map only the surficial or "shallow" fluid potential field of a groundwater system if full and reliable identification of the system is to be accomplished in terrane which may be underlain by rocks of high relative permeability. Most hydrologic data of groundwater potential are limited to close to the top of the zone of saturation, and hence even a detailed knowledge of the configuration of saturation may be woefully inadaquate to ascertain where some waters leave the system, or where they enter the system in areas underlain by permeable zones at depth. There is good evidence for extensive permeable zones at considerable depths with the carbonate rocks in eastern and southern Nevada.

Flow System Delineation In Carbonate Terrane

The evidence available suggests that thick sequences of carbonate rocks underlie most of the alluvial basins and much of the volcanic rock sequences of eastern Nevada. Deep petroleum wildcat drilling indicates that intervals of cavernous carbonate rock exist to depths perhaps greater than 10,000 feet, as many test holes experienced extreme circulation difficulties, and a few have experienced dropping bits upon encountering caverns (see Appendix IV).



A and B - Situation of interbasin flow produced by greater relative permeability at depth and relief.

C - Situation of interbasin flow produced by relief alone, in uniform permeability media.

D - Situation of interbasin flow created by lense of permeability material.

← - Flow line

---- - Equipotential line

K - Relative Hydraulic Conductivity

Figure 2. Models of Configuration of Flow with Varying Boundary Conditions (Modified after Freeze and Witherspoon, 1967)

A prime hydrologic evidence of extensive zones of permeability in carbonate bedrock is provided by a number of large important groundwater discharge areas. Impressive examples of valleys which must lose water by interbasin flow through the surrounding mountain ranges include Jakes Valley, Cave Valley, Coal Valley, Dry Lake and Delmar Valleys, Sand Springs Valley (also called Little Smoky Valley) and Long Valley. Many other basins in eastern and southern Nevada also are believed to lose groundwater by interbasin flow, but their smaller size or the limited availability of moisture for recharge makes the phenomenon of interbasin flow less impressive and, in some cases, less certain. The distribution of groundwater discharge areas in Plate III further illustrates this phenomenon of interbasin flow.

Groundwater Chemistry of Large Springs

There has been much work on the geochemistry of carbonate waters in recent years. The spatial variations have been investigated by such workers as Back (1966), Back and Hanshaw (1970), Jacobson and Langmuir (1970), and Langmuir (1971). Temporal variations have been studied by Shuster and White (1971, 1972), Thrailkill (1972), Jacobson (1973), Hess (1974) and Hess and White (1974). The geochemistry of carbonate waters is of interest in its own right and is also a means of investigating the hydrogeology and physical hydrology of an aquifer, including flow system delineation.

Maxey and Mifflin (1966) and Mifflin (1968) have demonstrated the apparent utility of water chemistry from large-discharge springs associated with flow systems in eastern Nevada. The quality of groundwater flowing through carbonate terrane will vary with length of flow path and residence time. The minerals calcite ($CaCO_3$) and dolomite $CaMg(CO_3)_2$ which form the major carbonate rock types of limestone and dolomite are soluble in water, but not as soluble as other minerals that might be associated with carbonate rocks such as gypsum ($CaSO_4$) and halite (NaCl). Concentrations of the various ions formed by solution of the above minerals will increase in the groundwater with length of flow path and time. However, Maxey and Mifflin demonstrated that water chemistry of springs believed to be associated with regional flow systems characteristically illustrated increased concentrations of sodium (Na), potassium (K), chloride (Cl) and sulfate (SO_4) with increased lengths of flow paths.

At each large spring associated with carbonate terrane, an indication of distance water has traveled, as well as the potential, temperature and character of discharge, can be obtained. This provides a powerful tool in the absence of widespread fluid potential data. Further, the temperature of water gives indication of probable depth of circulation immediately up-gradient from the spring. The elevation of the spring gives an indication of fluid potential at that point in the system. Character of discharge (i.e., either variable or constant) gives indication of proximity of significant recharge areas. All these attributes, if considered together, offer qualitative characterization of the involved flow system at that geographic point.

Tritium in Carbonate Springs

Tritium, a radioisotope of hydrogen, can be a useful tool in determining age and source of groundwater. Use is made of environmental tritium as a tracer.

Reconnaissance sampling for tritium in large carbonate springs was used by Mifflin (1968) to further investigate the character of carbonate rock flow systems. He found that the concentration of Na+K forms a reliable criterion for predicting tritium concentration in springs. Significant amounts of tritium were found in all sampled springs that contained less than 3.8 ppm Na+K. No significant amount of tritium was found in any sampled spring that contained more than 8 ppm Na+K.

Flow System Classification by Chemistry and Tritium

Variations in water chemistry and tritium in large springs associated with flow systems in carbonate terrane aid in flow system delineation. A classification was applied by Mifflin (1968) that divided springs into three general groups; 1) small local, 2) local and 3) regional flow systems. The approach was to consider water chemistry in springs known to be associated with systems that are interbasin in configuration (regional with long flow paths) and water chemistry in large springs which are intrabasin in configuration (local with short flow paths). Further, the occurrence of tritium in significant quantities in some springs permits a third classification with limits based on tritium.

On the basis of water chemistry and independent hydrologic data, relative paths of flow or lengths of flow systems in carbonate rock terrane were divided into two broad categories, local and regional systems. Occurrence of tritium in significant concentrations in waters with low concentrations of Na, K, Cl and SO_4 and consistent absence of significant tritium in waters with higher concentrations of these ions strongly support the characterization of flow systems into local and regional systems. It also indicates that very little or no recharge occurs near points of discharge of large springs associated with regional flow systems. Springs which contain significant concentrations of tritium may be separated further on that basis as being related to "small local" flow systems.

Figure 3 (modified from Mifflin, 1968) is a logarithmic plot of concentrations of Na+K ions compared with $Cl+SO_4$ ions found in the large springs associated with the carbonate rock terrane. Also shown are the discussed boundaries of flow system classification, the springs assayed for tritium, and the springs that displayed significant tritium. Appendix II is a compilation of physical and chemical characteristics of carbonate springs in eastern Nevada. It includes the data used to plot Figure 3.

Flow System Boundaries in Southern and Eastern Nevada

The flow system boundaries in southern and eastern Nevada were developed by Mifflin (1968) on the basis of both conventional hydrologic data and system classification studies of the large springs. Even with the combined approach, delineation of flow systems in this region is believed subject to major error, and truly confident delineation awaits the proof provided by carefully collected fluid potential data from deep wells in key areas.

Plate III illustrates the distribution of flow system boundaries and location of the regional springs associated with the carbonate rock terrane of eastern and southern Nevada, along with indications of flow direction and areas of possible interbasin flow. See Mifflin (1968) for more detailed discussions.

Most flow systems in southern and eastern Nevada are interbasin in configuration of flow. Confident delineation of flow system boundaries in this region cannot be accomplished in detail with available data; however, the general aspects of delineation shown in Plate III are more or less valid. The greatest problem of delineation in this region is location of flow system boundaries in areas where important flow occurs at depth in carbonate rock. Shallow fluid potential data may be misleading as to location of significant boundaries.

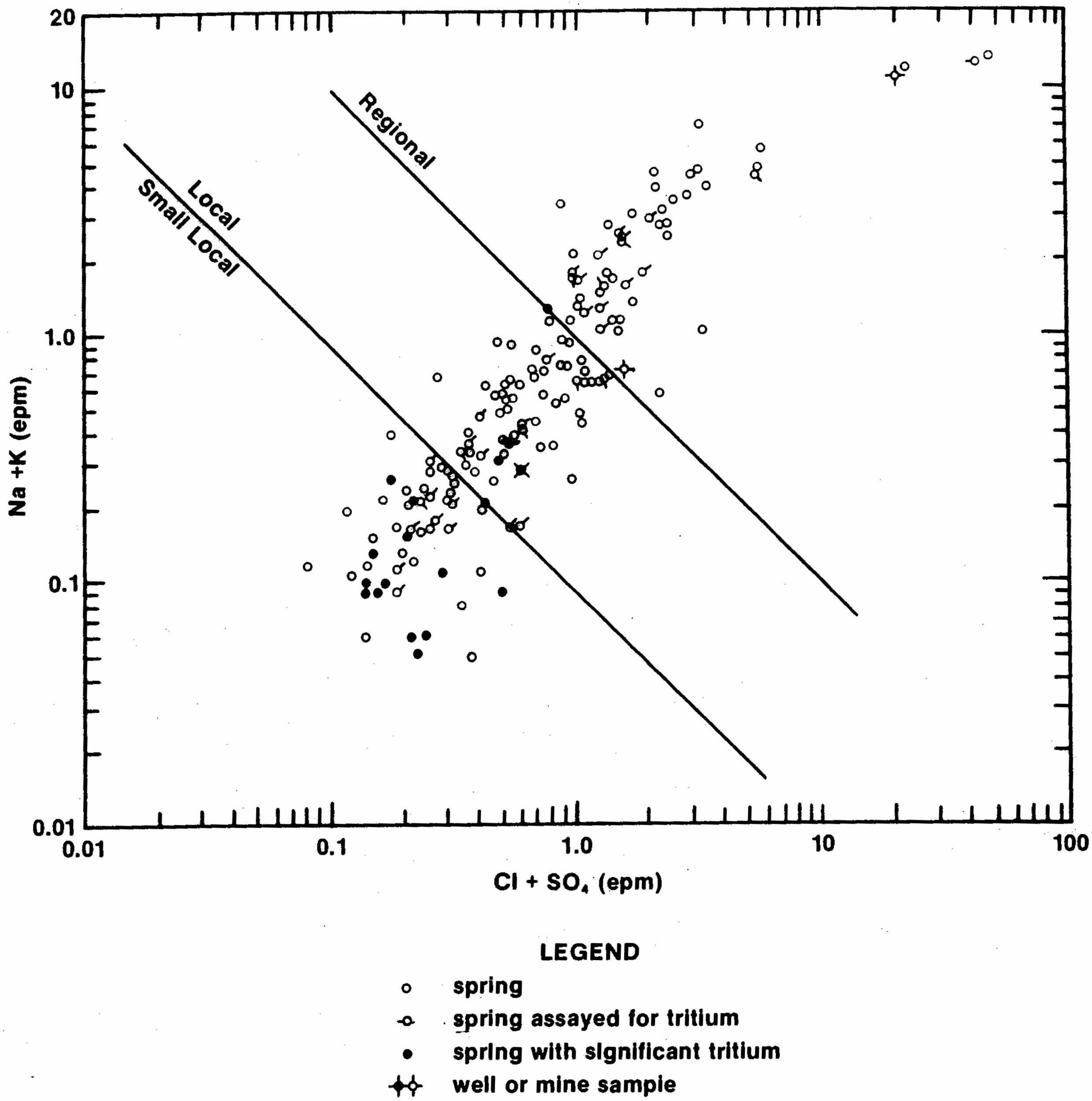


Figure 3. Plot of the Relation Between Water Chemistry, Tritium, and Spring Classification (Modified from Mifflin, 1968)

The four largest interbasin flow systems in eastern Nevada are White River, Railroad Valley, Las Vegas, and Amargosa Desert-NTS. Pahrump Valley-Mesquite Valley flow system has been classified as a local flow system in the Nevada portion, even though characteristics are very similar to the Las Vegas flow system. The boundaries of all these flow systems are uncertain in at least some areas. The chosen boundaries of these four systems in Plate III have been based on all available data, which include shallow fluid potential data, lithology, budget estimates and water chemistry in springs, but none of the evidence is believed powerful enough to delineate boundaries with confidence.

The importance of flow system delineation to the concept of potential development of carbonate aquifers for water supply is in the disciplines of economics, management and legal considerations. For example, it is known from radiometric age dating of some spring waters (Mifflin, 1968; Haynes 1967; Winograd and Pearson, 1976) that regional flow systems waters have rather long average travel times, as would be expected from other lines of evidence. Therefore, the great distances and slow travel times indicate that even though some conventionally developed groundwater basins may be supplied by the regional flow system, the time frame of connection is so great that thousand of years would be required for development in one area of the system to be manifested in a distant part of the system. Should it be decided to use these waters from the carbonate aquifers, it becomes important to find the most economical places to develop the waters without creating undesired impact on the existing groundwater development. Such considerations as pumping lifts, transfer distances, and perhaps aquifer exploration costs depend on reliable flow system delineation. At the present time, the evidence is strong enough to say that the large regional flow systems exist, the discharge areas are generally known, and there are many areas where carbonate aquifer groundwater could probably be intensely developed without short term (200 year) impact on conventional groundwater supplies. What is not known is just how close to conventional groundwater supplies such intense development might be without short term impact. Some very significant economic advantages could be overlooked if adequate flow system studies are not entered into prior to basic water resource development decisions in southern and eastern Nevada.

Summary

The carbonate rock province of Nevada is an area where the characteristics of flow systems are quite diverse and interbasin flow is common. Presently available data and techniques are adequate to roughly outline the flow systems in this region; however, these data and methods are not adequate to accurately delineate interbasin flow in many areas. Water chemistry in some large springs in the province suggests long flow paths (greater than 100 miles) and deep circulation in the carbonate rocks unrelated to configuration of shallow circulation. In these areas accurate delineation of interbasin flow will require fluid potential information from deep wells.

PERMEABILITY INDICATORS

In the absence of direct information on permeability of potential target zones, four different types of data have been used in this study to evaluate permeability in the carbonate rocks: 1) number and mapped length of solution caves, 2) carbonate springs, 3) petroleum wildcat wells, and 4) mines. This information has been compiled by geologic age, and is discussed below.

Caves

Solution caves are an extreme example of tertiary permeability in carbonate rocks. They are useful features as indicators of which carbonate strata are most susceptible to solution and in the interpretation of the paleohydrology of an area. However, it must be kept in mind that lithology is not the only control on cave development. Structure, stratigraphy and history also play major roles. Which of these factors is most important cannot be determined here. In any case, caves are used in this study as gross indicators of which carbonate units have a potential for high solutional permeability.

Appendix III lists by county the known solution caves in Nevada longer than 100 feet and includes the elevation, mapped length and lithologic unit. These cave locations are shown on Plate IV (from McLane, 1972 and 1974). The number of caves and total mapped cave length by geologic age are summarized in Table 2. Cambrian carbonate units contain the most caves (39) and the greatest total mapped cave length (23,000 ft.). Devonian carbonates follow with 14 caves and 5,000 feet. These two groups of carbonate strata contain 68% of the caves and 74% of the cave length. Thus the cave data suggest the Devonian and Cambrian strata have a high potential or solutional permeability.

TABLE 2

Cave Summary

Age	Number of Caves	Approximate Total Length (feet)	Comments
Cenozoic	2	700	
Cretaceous	0	0	
Jurassic	0	0	
Triassic	3	2000	
Permian	4	1800	
Pennsylvanian	1	1000	
Mississippian	5	1600	Monte Cristo Group in Clark County
Devonian	14	5000	Devil's Gate limestone in Elko County
Silurian	0	0	
Ordovician	10	2500	Pogonip Group in Nye County
Cambrian	39	23000	Pole Canyon limestone in White Pine County

* Data compiled from McLane (1972).

The comparison of the most cavernous units suggests the hydrogeologic history of the area may be a more important control on cavern development (permeability) than lithology (age of the rocks). However, it appears that within a given area (county) certain lithologic units are the best cave formers.

Wildcat Petroleum Wells

The records at the Nevada Bureau of Mines and Geology, including Reports 18 and 29 and Bulletin 52, were searched for information on the petroleum wildcat wells in eastern Nevada concerning zones of lost circulation, water production and fractures in the carbonate bedrock. In addition, contacts were made with major petroleum exploration companies to obtain additional information on selected wells of special interest. The petroleum wildcat wells are plotted on Plate IV. Appendix IV lists these wells, including: surface elevation, elevation of the top of the carbonate, thickness of the alluvium, total depth of the well, formation or age of the top of the carbonate, thickness of carbonate rocks penetrated, and indications of permeability. Those wells with indicated permeability are plotted as black dots on Plate IV. There are 193 wells listed in Appendix IV and shown on Plate IV. Of these, 33 have indicated zones of high permeability. This is a minimum number, since complete records have not been searched on all wells.

Table 3 summarizes the geologic age for indications of high permeability. The table contains 19 entries; no lithologic data were available for the other 14 wells where permeability was indicated. The lack of permeability indications in the Silurian, Ordovician or Cambrian probably reflects the lack of data rather than the lack of permeability.

TABLE 3

Number of Petroleum Wildcat Wells
with Permeability Indications

Age	Number of Wells
Permian	3
Pennsylvanian	6
Mississippian	7
Devonian	3
Silurian	0
Ordovician	0
Cambrian	0

Carbonate Springs

Appendix II is a compilation of physical and chemical spring data from many different sources. The available lithologic data have been summarized in Table 4. The rock unit associated with the discharge point of the spring does not necessarily indicate the strata in which the water is flowing at depth. It does, however, indicate permeability in that particular unit, at least at the land surface. Many of the same constraints must be kept in mind when evaluating the spring data, as with cave data. Structure and history are also important factors controlling which unit the spring discharges from.

TABLE 4

Geologic Age of Rock Units
Associated with Carbonate Springs

Age	Regional Springs	Local and Small-Local Springs	Total
Permian	1	4	5
Pennsylvanian	4	10	14
Mississippian	2	4	6
Devonian	15	23	38
Silurian	3	1	4
Ordovician	1	6	7
Cambrian	11	20	31

Table 4 indicates that the largest number of springs are associated with the Devonian carbonates. Fifteen regional and 23 local or small-local springs discharge from Devonian rocks. Cambrian units have 11 regional and 20 local or small-local springs associated with them. As with the cave data, these two geologic rock units have the highest permeability as indicated by springs. They represent 70% of the total regional springs and 66% of the total number of springs.

Mines

During the search of the geologic literature, many references were found that indicated caves or water in mines. No attempt was made to summarize the data due to limited specifics. However, water was a problem in many mines and many caves were encountered, indicating not only the presence of water at depth, but relatively high permeabilities in the area of the mines. Some dewatering attempts have failed due to high permeabilities in carbonate rocks.

Summary

The cave, wildcat well and spring permeability data have been summarized in Figure 4. A number of permeability indicators have been plotted against geologic age in a bar graph. The Cambrian and Devonian carbonate units are most frequently associated with permeability indicators selected, based on the data available. This is compatible to the hydrostratigraph classification for southern Nevada (Table 1) developed from NTS studies. The Lower Carbonate Aquifer in Table 1 includes the rocks between the Cambrian and Devonian. It is described as a complexly fractured aquifer with coefficents of transmissibility ranging from 1,000 to 1,000,000 gpd/ft.

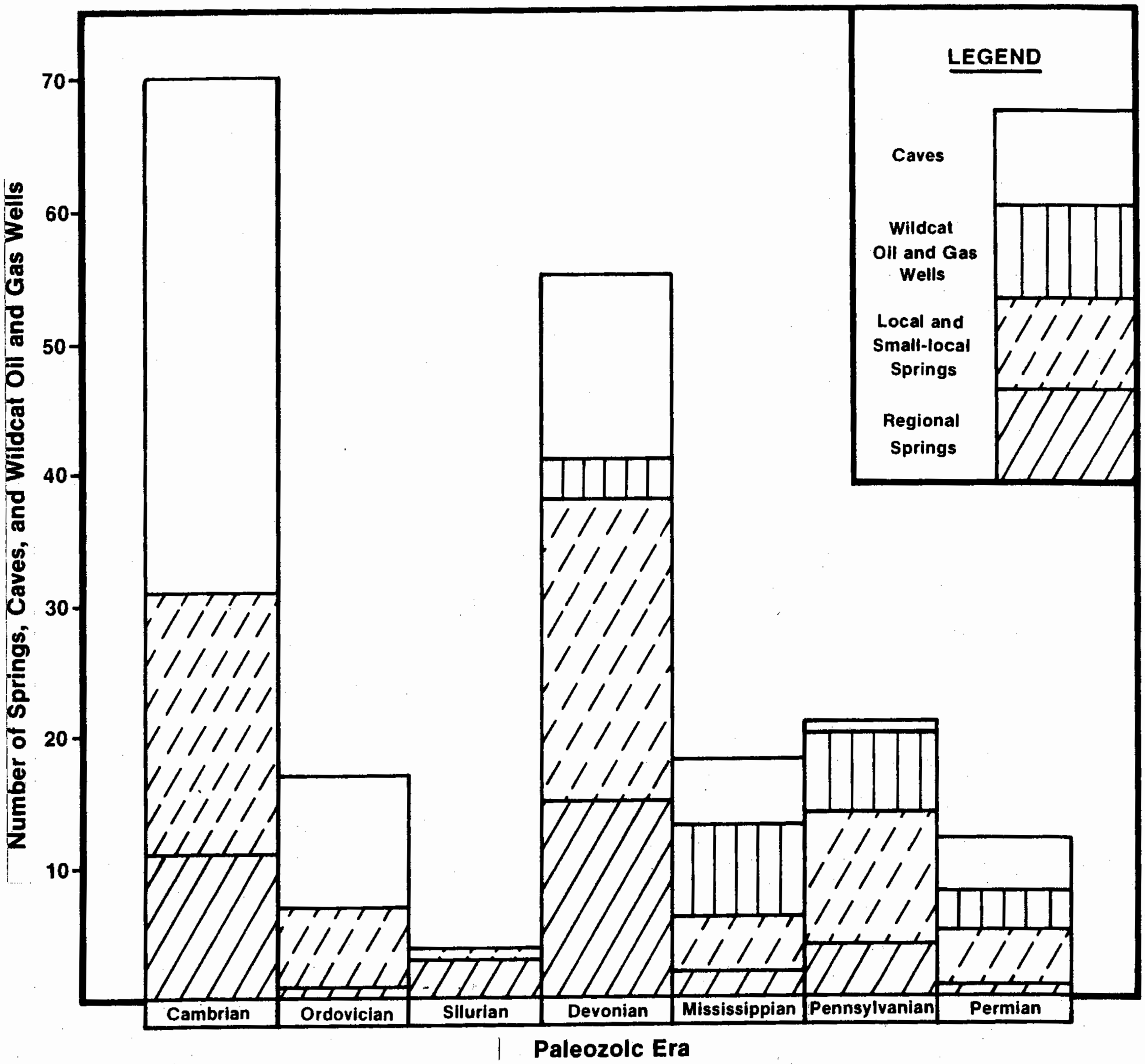


Figure 4. Permeability Data Sources by Geologic Age

EXPLORATION PLAN

Introduction

Phase II of the "Deep Hole" project is designed to gain an understanding of large regional carbonate aquifers in the Great Basin and to explore their potential for future municipal and other water supply purposes. That phase of the work will involve subsurface data collection through the use of wildcat oil and gas wells and from other wells drilled specifically for project purposes as part of the overall effort. A proposal has been developed for Phase II and was submitted to the U.S. Department of Interior for funding. Copies of the proposal are available for review at the Desert Research Institute. The proposal has been reviewed by the U.S. Geological Survey, where it received an excellent technical rating, but was placed low on the priority list for funding. Efforts are being continued to obtain funding. The proposal outlines the exploration plan, summarized below with added specifics not in the proposal.

Phase II Proposal Objectives

The objectives of Phase II are quoted below from the proposal:

"The overall objective of this research is to gain a better understanding of the deep regional carbonate flow system in the Great Basin. Within this broad view, specific objectives are:

1. Determine the dynamic recharge/discharge/storage characteristics of the regional flow system.
2. Determine quantity and quality of water that may be available from the regional carbonate aquifers.
3. Determine the physical aquifer characteristics of the system.
4. Predict hydrologic effects of potential withdrawals on the regional flow systems.
5. Determine best areas for economic development of the groundwater in terms of flow system dynamics.
6. Determine potential conflicts with existing surface and groundwater rights and develop criteria for changes that may be required for consideration by appropriate policy-making entities.
7. Design a monitoring network to observe effects of development on the regional flow system."

General Research Plan

The Phase II research effort will be divided between two major task areas, with a final third task designed to pull the whole effort together. The first task will be to investigate the functioning of large regional carbonate flow systems in the Great Basin. Recharge, discharge and storage characteristics will be studied along with the various hydrogeologic boundary conditions. Task two is designed to acquire new subsurface data through the use of petroleum wildcat and exploratory test holes. Task three, due to the diversity in lines of investigation involved and the probable number of reports and distinct investigations, is believed to be advisable in terms of placing results into usable form for decision-making purposes. A technical advisory panel will be designated to assist in the conduct of this research.

Task I - Regional Aquifer Systems

This task will study the hydrogeologic boundary conditions and dynamic functioning of regional carbonate flow systems. Groundwater recharge, discharge, movement and aquifer properties will be investigated through use of discharge and chemical hydrographs. Spring inventories will be done to assess discharge characteristics. Physical and chemical models may be built to aid in understanding the flow systems. The relationship between the carbonate and alluvial aquifers will be investigated.

Another part of this task will be an extension of work reported herein. Efforts will continue to assemble and interpret existing geologic, geophysical, hydrologic and geochemical information available on the Great Basin carbonate rock province of eastern Nevada and western Utah.

A third part of this task will be to assemble and interpret, within the context of knowledge gained in past and new spring studies, the water quality and fluid potential data that become available through the subsurface data aquisition task described below. For example, past work indicates probable boundary areas of regional flow systems, water chemistry characteristics, and general relations of fluid potential that should exist if delineation of flow system boundaries is correct. As subsurface data become available, marked advances in confidence of delineation and basic understanding should be possible.

Task II - Subsurface Data Acquisition

Final validation of the hypothesis that deep carbonate aquifer systems exist well beyond the very limited areas of hard data will require successful collection of subsurface data. Two sources of subsurface data collection are envisioned: 1) wildcat oil and gas wells and 2) exploration test wells.

Through contacts with oil and gas operators, it has been determined that there is the possibility of DRI or other agencies being given, for testing and monitoring purposes, holes drilled for oil and gas testing during and after such drilling. One requirement would be that the recipient assume legal responsibility for properly plugging said holes in accordance with all regulations, as appropriate. Mutually acceptable contracts will be entered into, as needed, with oil and gas operators for possible hydraulic testing of exploration holes. The eastern Great Basin is the object of high interest in petroleum exploration circles at this time; many hundreds of thousands of acres of Federal oil and gas leases are tied up, and as many as fifty exploratory holes are contemplated in the next two years (1978 and 1979). The general indication from oil operators is that they are very interested in this project and will be very willing to cooperate in terms of data, advice and assistance. These possibilities are being explored further at this time.

The use of wildcat test holes for purposes of this project will greatly expand the data base on subsurface conditions and reduce the overall project cost from what it would be if all test holes were to be drilled from scratch. Also, once the petroleum testing is completed the hole could then be finished as a monitoring well.

Based on the results of the concurrent aquifer systems analysis studies and the adequacy of data from wildcat test holes, additional exploratory test holes may be necessary to further the understanding of the regional flow system. The key information to be obtained from these holes would be fluid potential measurements with depth and structural controls on permeability. Test holes must be large enough (>14") to get pumps down for possible high volume pump tests.

The type of holes necessary will be expensive, with depths that may range from 2,000 to 10,000 feet. These holes cannot be drilled with "water well" drill rigs, but rather must be drilled with oil field equipment. The objectives of exploratory holes is not simply to determine the existence and depth of aquifers but also to develop data on the hydrologic and geologic properties of the various formations penetrated, and to collect water samples for chemical analysis and age date determinations. These objectives necessitate a hole diameter large enough to accommodate geophysical logging instruments, straddle packers and pump-test hardware. This drilling and testing philosophy differs from that found in the "oil patch" where the principal concern is existence of hydrocarbons, which, if found, are produced through a slim string of production tubing in a relatively small diameter cased hole. Compared to the volume of fluid extracted for an economically producing oil well, the volume of water produced from a water supply well is orders of magnitude larger. Thus permeability and production capacity are vital information needed from a hydrologic exploration hole.

Fluid potential data is also of high value, and is almost totally absent on a carefully collected basis in intermediate and deep subsurface environments. Mifflin (1968) discusses the potential value of such data from a deeply penetrating well with respect to recognizing and verifying flow system boundaries, positions, and possible circulation cells, based on limited field observations. These data, combined with water chemistry and age dating data, have the potential to verify concepts based at present on strong but indirect evidence.

Target Horizons

At present, there are some data which indicate the viability of attempting to choose well sites with respect to specific target horizons or formations. Conversely, there is much evidence that argues strongly for a more general approach of locating test drilling aimed at penetration of thick sequences of carbonate rock without regard for specific target horizons. It is this second approach that is used in the proposed exploration plan.

Aquifers

Support for more general target horizons is the known distribution of permeable zones as shown in Figure 4. Caves and springs dominate in the Cambrian and Devonian rocks, but are present throughout the entire carbonate section. Wildcat oil and gas wells also have indicated high permeability zones throughout their penetrated thickness. Therefore, a drilling program should try to penetrate a thick sequence of carbonate rock first and secondarily aim for the so-called lower carbonate aquifer. Groundwater potentials are difficult to estimate with limited data available. However, one well in White Pine County which was drilled to a depth of 10,314 feet had a fluid level of 1,025 feet below land surface which could not be bailed down. Total dissolved solids in the water, from data supplied by Continental Oil Company, were approximately 1900 mg/l.

Structural and Stratigraph Aspects

Structure is generally extremely complex in most of the carbonate rock province of eastern Nevada, with folding and various types of faulting making prediction of subsurface strata difficult. Further, facies changes are rather common in many of the carbonate rock sequences, making lithologic characteristics quite variable in a regional sense. Thrust faulting, high angle reverse faults and low angle over-thrusts tend to dominate the structure of many of the ranges, and also to make prediction of subsurface sequences in the basinward environments very unreliable. Basin and range normal faulting may provide a basis for site specific location of test holes on the theory that the more youthful fault activity should create more permeable fracture zones and more open zones for active circulation of water.

The abundant low and high angle thrust faults create the conditions of repeated sequences of rocks, and raise great uncertainty in predicting subsurface position of various formations. In areas of extreme deformation, test drilling may best be controlled by seeking drilling environments where structure is known in the upper parts of the test hole. This will require careful site selection, where carbonate rocks outcrop in basins and environs.

Based on the indirect evidence of drilling fluid circulation return problems in wildcat oil and gas wells, the most practical approach for test drilling seems to be based on penetration of thick sequences of carbonate rock. Test drilling should be located to penetrate several thousand feet of carbonate rock, which is possible in numerous areas of eastern and southern Nevada.

Depth to Target Horizons

The depth to thick sequences of carbonate rock is quite variable throughout eastern Nevada. Table 5 lists by county the average and range of alluvial and carbonate thickness penetrated by wildcat oil and gas wells. Alluvium ranges to greater than

10,000 feet thick. Drilling test holes in the basins could mean penetrating several thousand feet of alluvium before hitting the carbonate strata. However, the depth to carbonate horizons could be minimized by drilling on the basin margins. Figure 5 is a stratigraphic cross section through eastern Nevada constructed from wildcat oil and gas well logs. Line of section is shown on Plate IV. It illustrates the variability in depth to the carbonate strata.

Thickness of Target Horizons

Thickness of the target horizons is also variable, as evidenced by wildcat drilling (Table 5 and Figure 5). The wildcat wells have penetrated from five feet to greater than 11,000 feet of carbonate rock. Total thickness of carbonate units beneath the valleys is difficult to estimate due to structural complications. In the vicinity of the Nevada Test Site the lower carbonate aquifer is approximately 15,000 feet thick and the upper carbonate aquifer is 3,600 feet thick (see Table 1).

Summary

The drilling program should attempt to penetrate a thick sequence of carbonate rock without regard for a specific target horizon. Holes should be placed where the structure and stratigraphy are known.

Water Quality

Water quality in the carbonate flow systems is in general good. It is low in total dissolved solids (TDS), based on carbonate spring analyses. Appendix II gives the chemical quality of carbonate springs in eastern Nevada. Total dissolved solids data are plotted on Plate III for the regional springs. Figure 6 gives the distribution of TDS for the regional springs. A majority of springs have a TDS between 300 and 600 mg/l. The average TDS for the 42 regional springs within the boundaries of flow systems in carbonate rock is 701 mg/l. The water quality is even better if the four springs with a TDS greater than 1000 mg/l are eliminated from the average. They are an anomalous group of springs near Lake Mead in Clark County whose chemistry is influenced by highly soluable minerals in the bedrock in the discharge area. With their removal, the TDS average is 466 mg/l.

Table 5

Comparison of Generalized Geologic Units Penetrated by Wildcat Oil and Gas Test Wells in Eastern Nevada

(all values in feet)

				Alluvium		Carbonates	
County	Number of Wells	Range of Well Depths	Average Well Depth	Range of Thicknesses	Average Thickness	Range of Thicknesses	Average Thickness
Clark	15	716-8508	3279	15-4503	2036	20-4033	1653
Nye	26	692-10,183	5933	0-10,155	5085	28-2740	848
White Pine	17	712-11,543	5480	0-5369	2295	5-11,543	3157
Elko	12	1546-13,116	5899	295-8033	3835	137-9226	2064
Lincoln	2	488-7024	3756	13-6630	3322	394-475	435

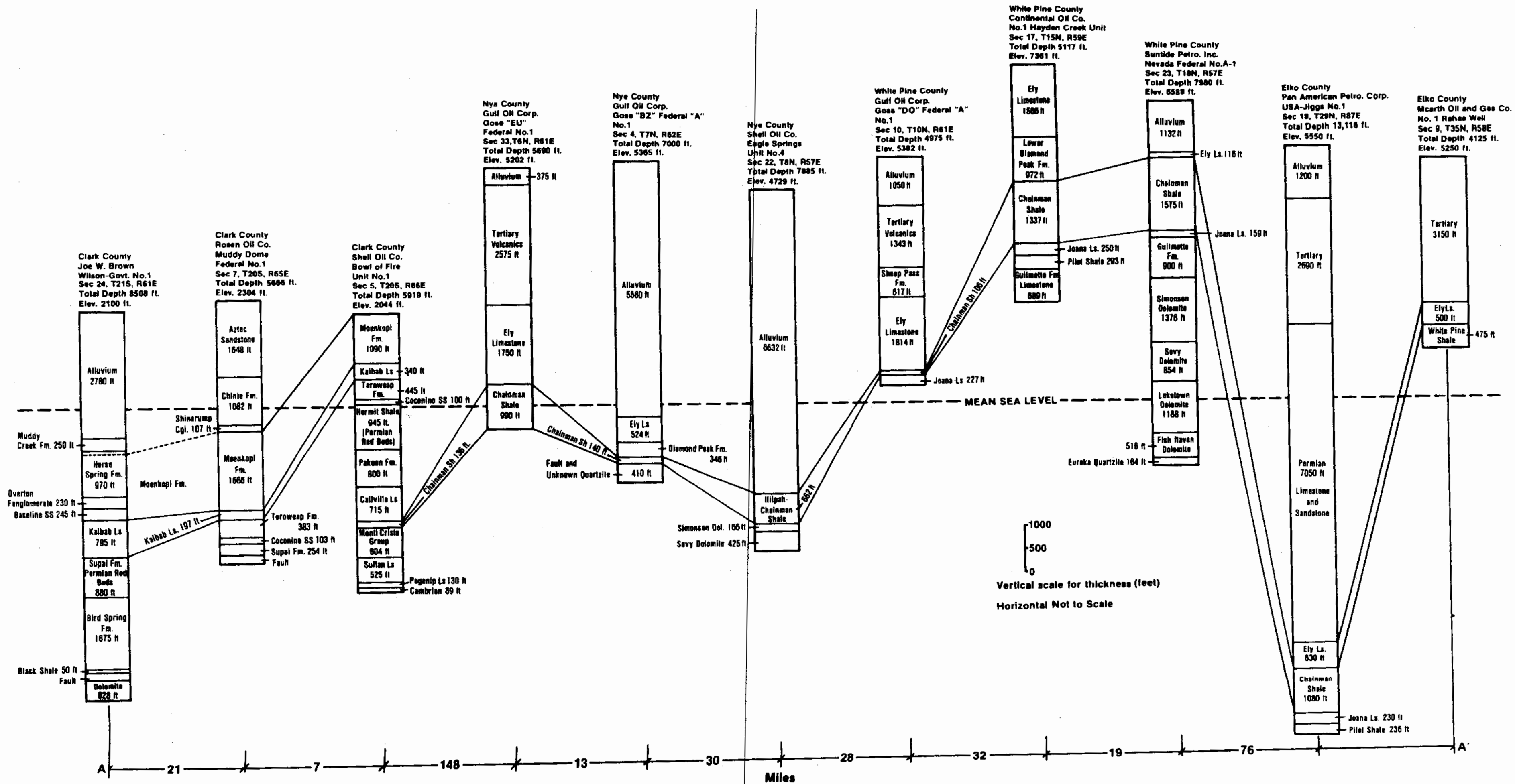


Figure 5. Eastern Nevada Stratigraphic Cross Section (Line A-A')
Data from Nevada Bureau of Mines: Bulletin 52, Reports 18 and 29

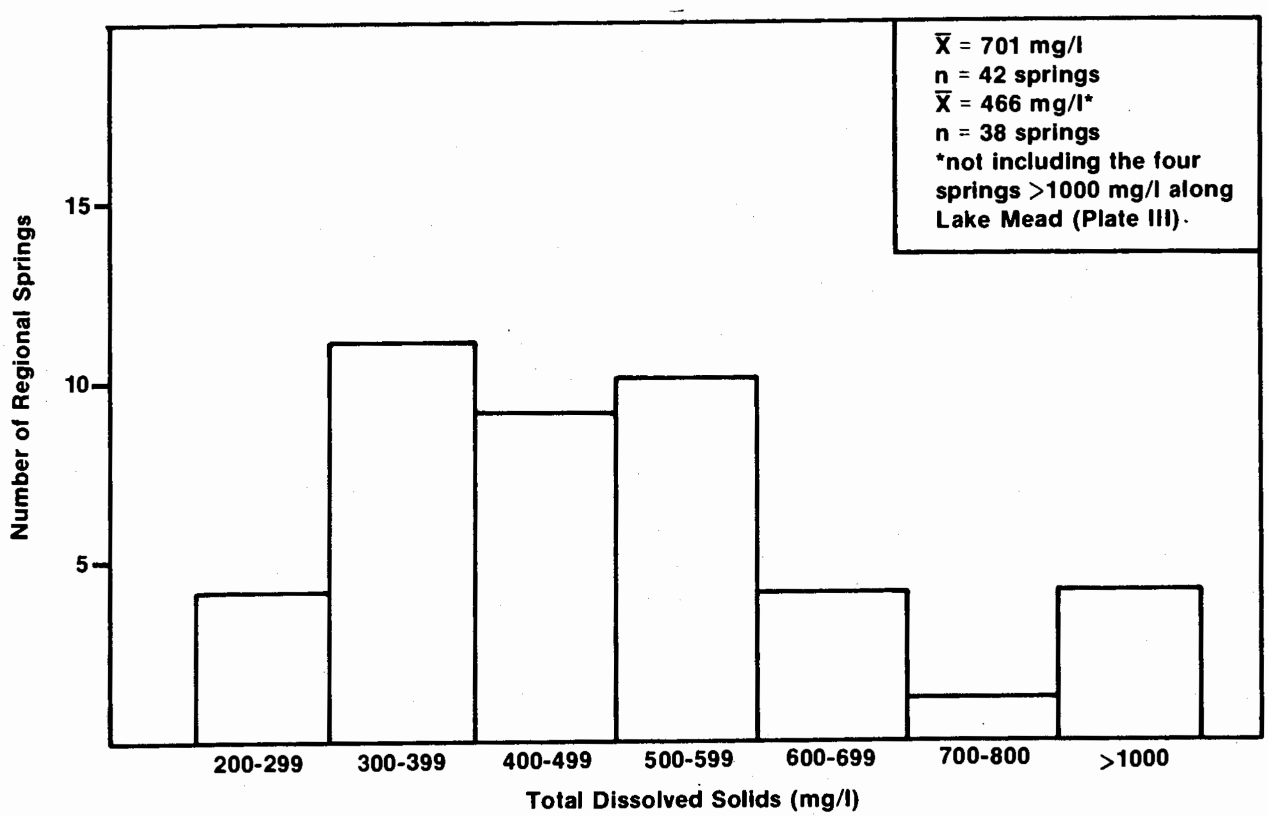


Figure 6. Distribution of Water-Quality in Regional Carbonate Springs

Data from Nevada Test Site wells (Winograd and Thordarson, 1975) indicate good water quality at depth. Total dissolved solids ranged from 328 to 439 mg/l in four wells at depths between 800 and 2,000 feet. However, data from two wildcat oil and gas wells in White Pine County indicate higher TDS. One well had a TDS of 1880 mg/l and the other up to 8700 mg/l. Therefore, water quality at depth in the carbonate rocks in general should be good if the well penetrates the zone of active circulation.

Bedrock - Alluvium Interaction

An important area of concern in the development of water supplies from the regional carbonate aquifers is the degree of communication between the alluvial aquifers, some presently used for water supply, and the carbonate aquifers. In at least one area of Nevada where there has been development of the alluvial aquifers, there is a demonstrated connection between the two systems. In Ash Meadows spring discharge decreased and water levels in Devil's Hole dropped in response to pumping of the alluvial aquifer (Bateman et al., 1972 and 1974). On the other hand, development of the alluvial aquifers in Moapa Valley have not changed the discharge of the Muddy River springs. There does not appear to be a connection that permits transmission of fluid potential changes between the two systems in that valley. From the data available, these interactions in most other areas are not known.

Drilling Program

The Phase II drilling program, as outlined in the proposal, would consist of two parts, wildcat oil and gas wells and exploratory drilling. Several sites for each of these parts are suggested below and shown in Figure 7.

Wildcat Oil and Gas Wells

The use of wildcat oil and gas test holes for deep aquifer investigations will greatly expand the data base on subsurface conditions and potentially reduce the number of exploratory and test holes drilled specifically for this project, thus reducing project costs. Wildcat test holes could also be used for monitoring purposes upon abandonment of the hole by the oil operators.

The question of which holes are to be used, what tests are to be performed,

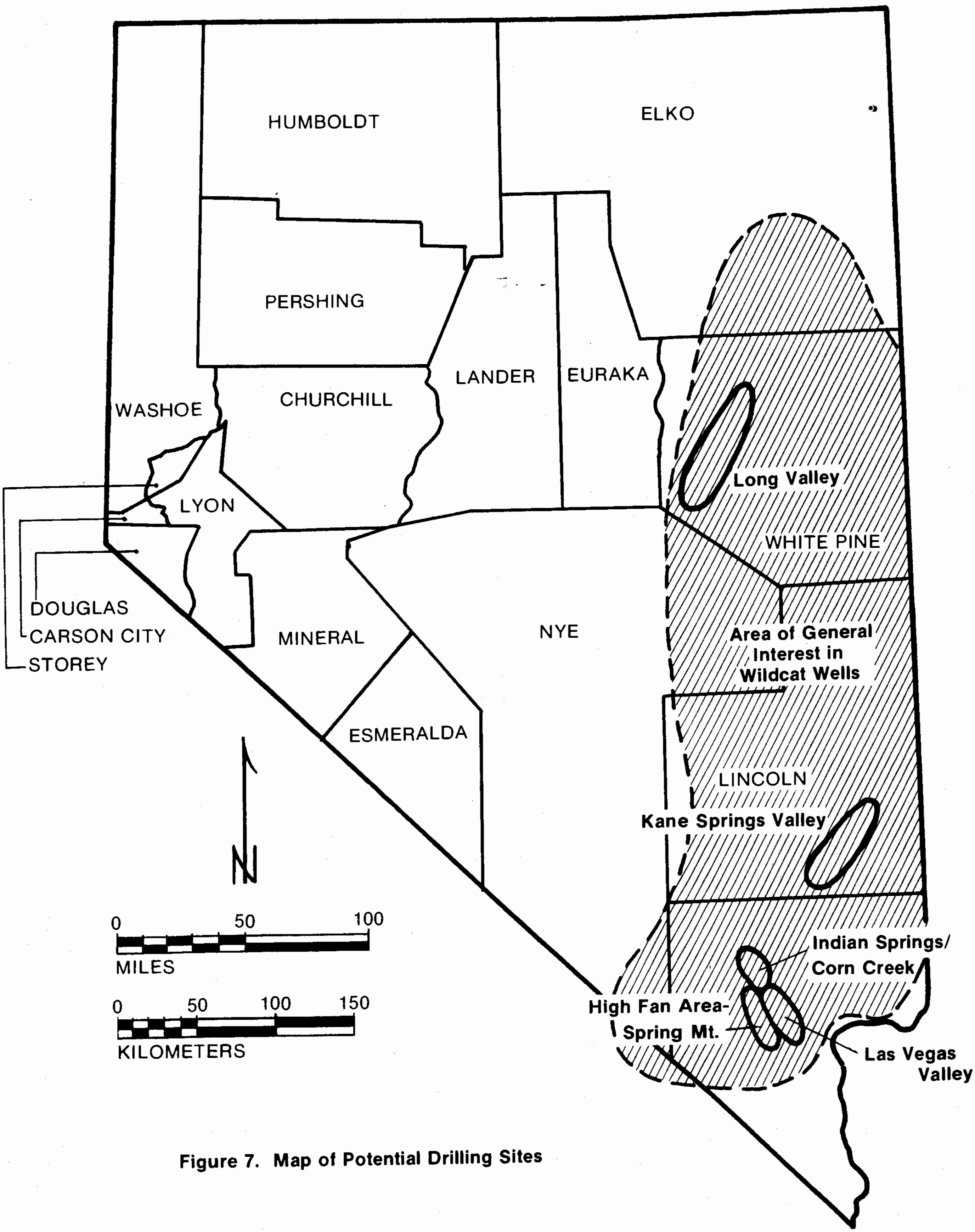


Figure 7. Map of Potential Drilling Sites

what data are to be collected and which holes are to be maintained as monitoring wells will be based on results presented herein and on newly collected data as part of Phase II.

It is projected that approximately seven wildcat test holes are to be obtained and used, starting in the first year of the five year project. Exact locations of these holes will depend on drilling activity by the oil and gas operators at the time. However, present data indicate that test holes drilled in Clark County would be most logical and beneficial because of the need to establish better subsurface data in the location of potential development. Lincoln and Nye county test holes would be of interest because of the present lack of data, particularly within the White River drainage. White Pine and southern Elko county holes would enable verification of data from a region with other good permeability indicators. Figure 7 outlines these areas of interest. It is proposed that, in addition to the usual data gathered by the oil and gas operators, hydraulic and water quality data be collected in zones of lost circulation before cementing. Various drill stem tests (Hackbarth, 1978) would be conducted in these zones of interest.

Exploratory Holes

Based on the results of the concurrent aquifer systems studies and the effectiveness of using the wildcat test holes, up to five exploratory holes will be drilled specifically for this project. They are projected to be drilled during the third and fourth years of the project, after collection of sufficient data to pinpoint locations of maximum data return. The U.S.G.S. is currently involved in a regional aquifer study of the Madison limestone aquifer in the northern Great Plains. See Brown et al. (1977) and Blankennagel et al. (1977) for drilling results obtained from their test holes. Five potential general areas are shown in Figure 7: 1) Las Vegas Valley, 2) between Corn Creek and Indian Springs, 3) Kane Springs Valley, 4) recharge areas and 5) Long Valley.

A test hole should ideally penetrate and produce data for the several high permeability zones likely to be encountered in several thousands of feet of carbonate rock penetration. For collecting the optimum amount of data, each zone of high permeability should be tested to some degree as the borehole initially encounters the zone and circulation of drilling fluid is partly or entirely lost. At this point, a drill stem test should be conducted as soon as possible, and an attempt made to establish fluid potential and permeability, plus water chemistry from that zone.

After such testing, the zone would have to be sealed in the conventional manner before drilling could be resumed. The procedure would be repeated for each zone of abnormally high permeability as the borehole is deepened. This means, however, that the hole so designed becomes less useful for actual pump testing for production purposes unless drilling is terminated in a highly permeable zone that is not sealed off. Probable procedure would be to attempt termination of drilling in such a zone to establish productivity through pump tests of one zone and the rest of the penetrated formation, less those zones which were cemented off to permit continued drilling. Water produced in such pump testing may be informative through water chemistry as to how much water production is being achieved from the termination zone, and how much from the rest of the open borehole in the carbonate rock sequence. Water quality data collected as the borehole was deepened would be the key to this type of analysis.

A consideration in design concepts for the hydrologic test holes is the need to develop hydrogeologic data on alluvial materials that overlie the carbonate aquifers. The data collected in this shallow system (hydraulic potential, permeability, etc.) will provide the basis for estimation of hydrologic communication and potential interference. To maintain separation between the alluvial and consolidated rock systems during drilling and testing of these holes, it will be necessary to install casing through the entire alluvial section. This casing will also ensure holding the upper portions of the hole open during the entire operation. In the consolidated rock, casing should not be required to hold the hole open. Holes will not be drilled to the predetermined depth, but instead will be terminated at that point at which it is decided that further drilling would be non-productive. In all instances, however, all available geophysical and geological data will be utilized in estimating probable depth to the carbonate system before drilling commences. The objective with each hole will be to maximize the hydrologic data and information obtained, both quantitatively and qualitatively.

Las Vegas Valley test and monitoring well. The objective of determining the degree and character of hydraulic connection between deep carbonate aquifers and the aquifers in overlying alluvial basins is extremely important. This is the key scientific objective which is essential to determining how intense exploitation could be, without jeopardizing conventional groundwater supplies. There are two basic approaches of field assessment: a) to observe fluid potential changes in the shallow aquifers when exploitation occurs in the deep carbonate aquifers, and b) to observe fluid potential changes in the deep aquifers as shallow aquifers are exploited. In the present situation, only the observation of deep aquifer fluid potentials is practical, and only in a few areas of Nevada does there seem reasonable opportunity to develop meaningful data. Las Vegas Valley offers the best opportunity, with a history of long term exploitation of the alluvial groundwater basin aquifers, and continuing development of a cone of depression of a magnitude sufficient to be transmitted to deep-seated carbonate aquifers should there be close, or direct, hydraulic connection.

Previous petroleum wildcat drilling has established some generalized knowledge of carbonate rock distribution in the Las Vegas Valley area. It is believed, based on several sources of information, that important amounts of recharge to the alluvium (in the west and northwesterly areas of the valley near Las Vegas) stem from carbonate rock aquifers. Further, if hydraulic connection is well developed, it would be pointless to install costly deep wells tapping the carbonate rocks to develop the same waters which ultimately reach the alluvial aquifers. However, if the hydraulic connection is measured in terms of hundreds or thousands of years for significant drawdowns to be transferred from one to the other of the systems (alluvial aquifers to carbonate rock aquifers, or visa versa), then the potential utility of deep carbonate aquifers relatively near Las Vegas becomes greatly enhanced in terms of water supply.

Therefore, part of the test drilling program is designed to penetrate the alluvial groundwater basin in Las Vegas Valley near the well developed northwesterly cone of depression. Water quality, transmissivities, spring locations, and surrounding structure suggest possible deep carbonate rock aquifers feeding the alluvium in this area. The initial test hole would be appropriately located near or in the Las Vegas Valley Water District well fields.

The objectives of such test drilling would be as follows:

1. Establish whether or not the area is underlain by permeable carbonate rocks and determine associated water quality.
2. If underlain by permeable carbonate rocks, finish the test hole in such a manner as to tap the upper-most permeable zones.

3. After appropriate sampling and pump tests, instrument hole for a monitoring program of fluid potential to establish the response of the deep aquifer to groundwater basin development in the overlying alluvial aquifers.

Should there be little or no response determined after several years of record, additional boreholes into that carbonate aquifer should be considered to substantiate the degree of hydraulic connection, or lack thereof. Such a program of monitoring should provide the basis for assessing the impact on the overlying groundwater basin should the deep aquifers be developed for groundwater supply.

Other test hole locations. Other test holes should be located to define flow system boundaries such as in the area between Corn Creek and Indian Springs and in Kane Springs Valley in southern Nevada.

A second general location would be recharge areas and the headward parts of flow systems. Holes could be drilled on the high fan areas, for example along the Spring Mountains, a recharge area for the Las Vegas Area or in Long Valley in White Pine County, which is in the headward part of a short regional system in an area with evidence of high permeability.

Exact locations of the exploratory test holes will be determined as the project develops, based on additional data and success of the use petroleum wildcat well data.

LEGAL IMPLICATIONS

There are two areas of legal concern regarding investigation of deep carbonate aquifers in Nevada. The first deals with exploratory holes and the second with production wells if the investigation and exploratory holes indicate that practical development is possible. Discussions with the Nevada State Engineer have determined the following:

In regard to exploratory holes, Nevada Revised Statutes chapter 534.180 (NRS 534.180) is clear. Exploration holes drilled only to collect geochemical, geological or geophysical data are exempt from provisions of chapter 534 or the regulations of the State Engineer. Therefore, a permit would not be needed for exploratory holes. However, under NRS 532.160 the State Engineer is mandated to review and evaluate proposals by federal, state and local agencies for water development projects to insure that such proposals are compatible with the state water resource plan and are in compliance with Nevada water laws. Therefore, the State Engineer should be apprised of all plans for the exploration or drilling of wells in the investigation of Great Basin regional carbonate groundwater flow systems. Further, any water encountered in the exploratory holes is subject to the appropriation procedures of chapter 534 of NRS.

As stated above, any water encountered in the exploratory drilling program would be subject to appropriation, as would water from production wells. In non-designated basins normal appropriation procedures would be followed. In any basin or portion thereof in the state designated by the State Engineer, he may restrict drilling of wells if he determines that additional wells would cause an undue interference with existing water uses. In determining if a basin should be designated or if withdrawals should be restricted, the State Engineer conducts investigations when it appears that the average annual replenishment to the groundwater supply may not be adequate for the needs of all permittees and all vested-rights claimants. NRS 534.120 provides that within an area designated by the State Engineer where, in his judgment, the groundwater is being depleted, he in his administrative capacity is empowered to make such rules, regulations and orders as are deemed essential for the welfare of the area involved.

NRS 534.110 provides that permits may be granted to applicants later in time even though the diversions under such proposed later appropriations may cause the water level to be lowered at the point of diversion of a prior appropriator, so long as the rights of holders of existing appropriations can be satisfied under such express conditions.

It appears, therefore, that should the results of the investigation of Great Basin regional carbonate groundwater flow systems prove that large amounts of water are available and withdrawal of these waters would not significantly lower the water table and prior appropriators could be satisfied, then appropriation of these waters might be accomplished, provided the State Engineer were to determine that the withdrawal and beneficial use of this water was essential for the welfare of the area. This may be an appropriate area for consideration by the Division of Water Planning under provisions of NRS 540.051.

All drilling conducted should conform to those rules prescribed by NRS 534.060 regarding casing and protection of various aquifers penetrated.

SUMMARY

The 12 month project which began September 1, 1977 was designed to assemble and interpret existing geologic, geophysical, hydrologic, and geochemical information available in areas of Nevada believed potentially favorable for development of water supply from carbonate rock aquifers. The project was the first phase of a conceptual multi-million dollar program to explore the potential of deep carbonate rock aquifers in southern and eastern Nevada for future municipal and other water supply purposes. Objectives of this first phase effort was to establish the most favorable areas for initial exploratory drilling and testing, and the objectives associated with such exploratory drilling.

Objective 1) Compile and interpret existing hydrologic, geologic, geochemical and geophysical data bearing on carbonate ground-water flow systems in eastern and southern Nevada with emphasis on the deep system in Clark County and environs. The data base has been found to be much larger than originally expected. As a consequence, not all of the data was used in meeting project objectives. As much data as possible was used within the constraints of this project. Approximately 570 geologic/hydrologic references have been cataloged, most have been skimmed for useful data and many have been carefully read and the data extracted. About 150 petroleum wildcat test hole records were inventoried which indicate many permeable zones and water bearing zones within the carbonates. An inventory of caves and large carbonate springs, along with their associated geologic units, has been compiled.

Carbonate rocks underlie approximately the eastern one-third of the state of Nevada (40,400 mi^2). Eastern Nevada lies within the miogeosynclinal belt of the cordilleran geosyncline, in which 30,000 to 40,000 feet of marine sediments accumulated during the Precambrian and Paleozoic. Two major periods of deformation have affected the region.

Cave, wildcat well and carbonate spring data indicate that the Cambrian and Devonian carbonate strata may generally have the highest permeability. This correlates with the lower carbonate aquifer hydrostratigraphic unit. Nothing has been found to reflect negatively on the concept of developing water from the deep carbonate flow systems.

Objective 2) Review potential water management implications in terms of existing state water law and implementation. Discussions have taken place with Roland Westergard, Nevada State Engineer, concerning the legal and institutional implications.

If the results of the investigation of Great Basin regional carbonate groundwater flow systems proves that large quantities of water are available and withdrawal of these waters would not significantly lower the water table and prior appropriators could be satisfied, then appropriation of these waters might be accomplished. The State Engineer must first, however, determine that the withdrawal and beneficial use of this water is essential for the welfare of the area.

Objective 3) Develop a comprehensive report that incorporates all available information. The present report is submitted as fulfillment of this objective.

Objective 4) Using above information, produce a detailed exploration plan and research program for future work as follows: a) develop maps indicating areas of most favorable locations for test and exploration wells, and b) determine exploration and test drilling program, including projected depths, drilling conditions and tests to be conducted.

The target horizon of the drilling program will be a thick sequence of carbonate rocks without regard for a specific unit. Holes should be placed where the starting structure and stratigraphy are known. Water quality at depth in the carbonate rocks in general should be good (TDS $\approx$ 300-600 mg/l). A major area of concern of the drilling program will be to establish the degree of interconnection between the carbonate aquifer and the alluvial aquifers.

It is projected to use approximately seven wildcat wells in the general areas of Clark County, White River drainage in Lincoln and Nye counties, and White Pine and southern Elko counties. Approximately five exploratory holes are projected to be drilled in Las Vegas Valley, Indian Springs, Corn Creek area, recharge areas, Kane Springs Valley and Long Valley.

Objective 5) Develop proposal(s) for subsequent phases of exploration drilling. A proposal entitled "Investigation of Great Basin Regional Carbonate Ground-Water Flow Systems" has been developed and submitted to the Honorable Cecil D. Andrus, Secretary, U.S. Department of Interior. This proposal has been reviewed by the U.S. Geological Survey, where it received an excellent technical rating but was placed low

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The Phase II research effort will be divided between two major tasks. The first will be to investigate the functioning of large regional carbonate flow systems in the Great Basin. Task two is designed to acquire new subsurface data through the use of petroleum wildcat wells and exploratory test holes.

BIBLIOGRAPHY

Abner, H., 1975. Geochemical analysis of carbonate rocks in the upper member of the Callville Formation (Pennsylvanian) Clark County, NV. M.S. thesis, Memphis State Univ.

Adair, D.H., 1961. Geology of the Cherry Creek district, NV. M.S. thesis, Utah Univ.

Adams, J.A.S., B.C. Burchfiel, G.A. Davis and J.F. Sutter, 1968. Absolute geochronology of mesozoic orogenies, southeastern Calif. GSA, Abs. for 1966, Spec. Paper 101, p. 1.

Addison, C.C., 1929. Stratigraphy and correlation of some carboniferous sections of Nevada and adjacent states. M.A. thesis, Stanford Univ.

Albers, J.P., 1967. Belt of sigmoidal bending and right-lateral faulting in the western Great Basin. GSA Bull., v. 78, p. 143-155.

Ammann, C.B., 1960. Case histories of analysis of characteristics of reservoir rock from drill-stem tests. Jour. Pet. Tech. 12:5, p. 27-36.

Anderson, R.E., 1971. Thin skin distension in tertiary rocks of southeastern Nevada. GSA Bull, v. 82, p. 43-58.

______, 1973. Large-magnitude late tertiary strike-slip faulting north of Lake Mead, NV. USGS, Prof. Paper 794.

Anderson, R.E., C.R. Longwell, R.L. Armstrong and R.F. Marvin, 1972. Significance of K-Ar ages of tertiary rocks from the Lake Mead region, Nevada-Arizona. GSA Bull., v. 81, p. 273-288.

Armstrong, R.L., 1963. Geochronology and geology of the eastern Great Basin in Nevada and Utah. Ph.D. thesis, Yale Univ. 202 p.

______, 1966. K-Ar dating using neutron activation for Ar analysis: granitic plutons of the eastern Great Basin, Nevada and Utah. Geochim. et, Cosmochim, Acta, v. 30, p. 565-600.

______, 1968. Sevier orogenic belt in Nevada and Utah. GSA Bull., v. 79, p. 429-458.

Armstrong, R.L. and E.C. Hansen, 1966. Cordilleran infrastructure in the eastern Great Basin. Am. Jour. Sci., v. 264, p. 112-127.

Atwater, T., 1970. Implications of plate tectonics for the Cenozoic tectonic evolution of western North America. GSA Bull., v. 81, p. 3513-3536.

Atwater, T. and H.W. Menard, 1970. Magnetic lineations in the northeast Pacific. Earth and Planetary Sci. Letters, v. 7, p. 445-450.

Atwater, T. and P. Molnar, 1973. Relative motion of the Pacific and North American plates deduced from sea-floor spreading in the Atlantic, Indian, and South Pacific Oceans. In Kovach, R.L. and A. Nur, eds., Proc. of the Conf. of Tectonic Problems of the San Andreas Fault System; Stanford Univ. Pubs. Geol. Sci., v. 13, p. 136-148.

Atwood, W., 1940. The physiographic provinces of North America. Ginn and Co. N.Y.

Avent, J.C., 1961. Geologic map of the Antelope Range, northeastern White Pine County, NV. Master's thesis, Washington Univ.

Back, W., 1961. Techniques for mapping of hydrochemical facies. USGS Prof. Paper 424-0, Art 423.

______, 1966. Hydrochemical facies and ground-water flow patterns in northern part of Atlantic Coastal Plain. USGS Prof. Paper 498A.

Back W. and B.B. Hanshaw, 1965. Chemical geohydrology; advances in hydrosciences. V. te Chow, ed., Academic Press, N.Y., p. 49-109.

______, 1967. Hydrogeology of the northern Yucatan Peninsula, Mexico. Field Trip to Peninsula of Yucatan Guidebook, 2nd Ed., New Orleans Geol. Soc., p. 64-78.

______, 1970. Comparison of chemical hydrogeology of the carbonate peninsulas of Florida and Yucatan. Jour. of Hydro. 10:330-368.

Barnes, H. and F.M. Byers, Jr., 1961. Windfall Formation (upper Cambrian) of Nevada Test Site and vicinity, NV. USGS Prof. Paper 424-C, Art. 188, p. C103-C106.

Barnes, H. and R.L. Christiansen, 1967. Cambrian and Precambrian rocks of the Groom District, NV. southern Great Basin. USGS Bull. 1244-G, p. G1-G34 (fig. 2).

Barnes, H., R.L. Christiansen and F.M. Byers, Jr., 1962. Cambrian Carrara Formation, Bonanza King Formation and Dunderberg Shale east of Yucca Flat, Nye County, NV. USGS Prof. Paper 450-D, Art. 127, p. 27-31.

Barnes, H., R.L. Christiansen, and F.M. Byers, Jr., 1965. Geologic map of the Jangel Ridge quadrangle, Nye and Lincoln Counties, NV. USGS Geol. Quad. Map GQ-363.

Barnes, H., F.N. Houser and F.G. Poole, 1963. Geologic map of the Oak Spring quadrangle, Nye County, NV. USGS Geol. Quad. Map GQ-214.

Barnes, H. and A.R. Palmer, 1961. Revision of stratigraphic nomenclature of Cambrian rocks, Nevada Test Site and vicinity, NV. USGS Prof. Paper 424-C, Art. 187, p. C100-C103.

Barosh, P.J., 1965. Lower Permian stratigraphy of east central Nevada and adjacent Utah. Ph.D. thesis, Univ. of Colo.

Barr, F.T., 1957. Paleontology and stratigraphy of the Pennsylvanian and Permian rocks of Ward Mountain, White Pine County, NV. M.A. thesis, Univ. of Calif.

Bartel, D.J., 1968. Structure and stratigraphy of the western Red Hills, east-central Nevada, White Pine County, NV. - Areal Geology. M.S. thesis, Univ. of Neb.

Bateman, R.L., 1976. Inventory and chemical quality of ground water in the White River - Muddy River - Meadow Valley Wash area, southeastern NV. Desert Res. Inst., WRC, PR 40, 45 p.

Bateman, R.L., A.L. Mindling, R.L. Naff and J.M. Joung, 1972. Development and management of ground-water and related environmental factors in arid alluvial and carbonate basins in southern Nevada. Desert Res. Inst., WRC, 18, 43 p.

Bateman, R.L., A.L. Mindling and R.L. Naff, 1974. Development and management of ground water in relation to preservation of desert Pupfish in Ash Meadows, southern Nevada. Desert Res. Inst., HW 17, 39 p.

Baver, H.L., Jr., J.J. Cooper and R.A. Breitrick, 1960. Porphyry copper deposits in the Robinson Mining District, White Pine County, NV. in IAPG Guidebook, p. 220-228.

Beal, L.H., 1965. Geology and mineral deposits of the Bunkerville District, Clark County, NV. NV Bur. Mines Bull. 63.

Behnke, J.J., 1961. Geology of the southern portion of Martins Ridge, Monitor Range, Nye County, NV. M.S. thesis, NV Univ.

Bereskin, S.R., 1969. Carbonate petrology and biostratigraphy of the Sultan Limestone (Devonian), eastern California and southern Nevada. Ph.D. thesis, Univ. of Calif.

Berge, J.S., 1960. Stratigraphy of the Ferguson Mountain area, Elko County, NV. M.A. thesis, Brigham Young Univ.

Bissel, H.J., 1960. Eastern Great Basin Permo-Pennsylvanian strata - preliminary statement. Am. Assoc. Pet. Geo. Bull., v. 44, no. 8, p. 1424-1435.

______, 1961. Eastern Great Basin Permo-Pennsylvanian strata - additional statement. Am. Assoc. Pet. Geo. Bull., v. 45, no. 8, p. 1510-1511.

______, 1962a. Pennsylvanian and Permian rocks of Cordilleran area, in Branson, C.C., ed. Pennsylvanian System in the U.S. - A symposium: Am. Assoc. Pet. Geo., p. 188-263, Tulsa, Okla.

______, 1962. Permian rocks of parts of Nevada, Utah and Idaho. Geol. Soc. Am. Bull., v. 73, no. 9, p. 1083-1110.

______, 1964. Ely, Arcturus, and Park City Groups (Pennsylvanian and Permian) in eastern Nevada and western Utah. Am. Assoc. Pet. Geol. Bull., v. 48, no. 5, 565-636.

______, 1970. Realms of Permian tectonism and sedimentation in western Utah and eastern Nevada. Am. Assoc. Pet. Geol. Bull., v. 54, p. 285-312.

Blankennagel, R.K., W.R. Miller, D.L. Brown and E.M. Cushing, 1977. Report on preliminary data for Madison Limestone test well No. 1, NE 1/4, SE 1/4, Sec. 15, T.57N, R.65W, Crook County, Wyoming. USGS, Open File Rept. 77-164, 97 p.

Blue, D.M., 1960. Geology and ore deposits of the Lucin Mining District, Box Elder County, Utah, and Elko County, NV. Master's thesis, Utah Univ.

Boettcher, J.W. and W.W. Sloan, Jr., eds., 1960. Guidebook to the geology of east central NV. Intermountain Assoc. of Pet. Geol., 11th Ann. Field Conference.

Bortz, L.C., 1959. Geologic map of the Copenhagen Canyon area, Monitor Range, Eureka County, NV. M.S. thesis, Univ. of NV.

Bower, B., E.H. Pampeyan and C.R. Longwell, 1958. Geologic map of Clark County, NV. USGS Min. Inv. Field Studies Map MF-138.

Brew, D.A., 1961a. Relation of Chainman Shale to Bold Bluff thrust fault, southern Diamond Mountains, Eureka and White Pine Counties, NV. USGS Prof. Paper 424-C, Art. 191, p. C113-C115.

_______, 1961b. Lithologic character of the Diamond Peak Formation (Mississippian) at the type locality, Eureka and White Pine Counties, NV. USGS Prof. Paper 424-C, Art. 190, p. 110-112.

Brill, K.G., Jr., 1963. Permo-Pennsylvanian stratigraphy of western Colorado Plateau and eastern Great Basin regions. Geo. Soc. Am. Bull., v. 74, no. 3, p. 307-330.

Bradley, W.G., 1932. Methods and costs of mining and crushing gypsum at the mine of the Blue Diamond Corporation, LTD., Arden, NV. U.S. Bur. Mines Inf. Circ. 6615.

Brokaw, A.L., 1967. Geologic map and sections of the Ely quadrangle, White Pine County, NV. USGS Geol. Quad. Map GQ-697, scale 1:24,000.

Brokaw, A.L. and P.J. Barosh, 1968. Geologic map of the Riepetown quadrangle, White Pine County, NV. USGS Geol. Quad. Map GQ-758, scale 1:24,000.

Brokaw, A.L., H.L. Bauer, Jr. and R.A. Breitrick, 1973. Geologic map of the Ruth quadrangle, White Pine County, NV. USGS Geol. Quad. Map GQ-1078, scale 1:62,500.

Brokaw, A.L. and T. Heidrich, 1966. Geologic map and sections of the Giroux Wash quadrangle, White Pine County, NV. USGS Geol. Quad. Map GQ-476, scale 1:24,000.

Brokaw, A.L. and D.R. Shawe, 1965. Geologic map and sections of the Ely 3 SW quadrangle, White Pine County, NV. USGS Misc. Geol. Inv. Map I-449, scale 1:24,000.

Brown, D.L., R.K. Blankennagel, J.F. Busby and R.W. Lee, 1977. Preliminary data for Madison Limestone test well 2, SE 1/4, Sec. 18, T1N, R54E, Custer County, Montana. USGS Open File Rept. 77-863, 135 p.

Buckley, C.P., 1967. Structure and stratigraphy of the Kingsley Mountains, Elko and White Pine Counties, NV. Master's thesis, San Jose State Coll., Calif.

Burchfiel, B.C., 1964. Pre-cambrian and Paleozoic stratigraphy of Specter Range quadrangle, Nye County, NV. AAPG Bull., v. 12, p. 40-56.

_______, 1965. Structural geology of the Specter Range quadrangle, NV, and its regional significance. GSA Bull., v. 76, p. 175-192.

_______, 1966. Reconnaissance geologic map of the Lathrop Wells quadrangle, Nye County, NV. USGS Misc. Geol. Inv. Map I-474, scale 1:62,500.

Burchfiel, B.C. and G.A. Davis, 1971. Clark mountain thrust complex in the Cordillera of southeastern California. Geologic Summary and Field Trip Guide. Calif. Univ., Riverside, Campus Mus. Contr., no. 1, p. 1-28 (Elders, W.A., ed.).

_______, 1972. Structural framework and evolution of the southern part of the Cordilleran orogen, western U.S. Am. Jour. Sci., v. 272, p. 97-118.

Burchfiel, B.C., R.J. Fleck, D.T. Secor, R.R. Vinclette and G.A. Davis, 1974. Geology of the Spring Mountains, NV. GSA Bull. v. 85, p. 1013-1022.

Burchfiel, B.C., P.J. Pelton and J. Sutter, 1970. An early Mesozoic deformation belt in south-central Nevada - southeastern California. GSA Bull., v. 81, p. 211-215.

Burton, W.D., 1962. Geology of the western part of the La Madre Mountain area, Clark County, NV. M.A. thesis, Univ. of Calif., L.A.

Byers, F.M., Jr., H. Barnes, F.G. Poole, and R.J. Ross Jr., 1961. Revised subdivision of Ordovician system at the Nevada Test Site and vicinity, NV. USGS Prof. Paper 424-C, Art. 189, p. 106-110.

Byrd, W.J., 1970. Geology of the Ely Springs Range, Lincoln County, NV. Wyoming Geol. Assoc. Earth Sci. Bull., June 1970, v. 3, no. 2, p. 23-32 (fig. 3).

Callaghan, E. 1937. Geology of the Delamar district, Lincoln County, NV. Univ. of NV. Bull., v. 31, no. 5.

_______, 1939. Geology of the Searchlight Mining District, Clark County, NV. USGS Bull. 906-D, p. 135-188.

Carpenter, E., 1915. Ground water in southeastern Nevada. USGS Water Supply Paper 467.

Carss, B.W., 1962. A lithological and environmental study of the Ely Spring Dolomite, Arrow Canyon Range, NV. M.S. thesis, Univ. of Ill.

Cebull, S.E., 1967. Bedrock geology of the southern Grant Range, Nye County, NV. Ph.D. thesis, Washington Univ., Modified by Kleinhampl, F.J. and J.I. Ziony, county map.

Chamberlin, T.L., 1975. Stratigraphy of the Ordovician Ely Springs Dolomite in the southeastern Great Basin, Utah and NV. Ph.D. thesis, Univ. of Ill.

Charkin, M. Jr., 1963. Graptolite beds in thrust plates of central Idaho and their correlation with sequences in NV. Am. Assoc. Pet. Geol. Bull., v. 47, no. 8, p. 1611-1623.

Chilingar, G.V., and H.J. Bissell, 1957. Mississippian Joana Limestone of Cordilleran miogeosyncline and use of Ca/Mg ration in correlation. Am. Assoc. Pet. Geol. Bull., v. 41, no. 10, p. 2257-2274.

Clark, D.L. and J.H. Becker, 1960. Upper Devonian correlations in western Utah and eastern NV. Geol. Soc. Am. Bull., v. 71, no. 11, p. 1661-1674.

Clark, D.L. and R.L. Ethington, 1964. Age of the Roberts Mountains Formation (Silurian?) in the Great Basin. Geol. Soc. Am. Bull., v. 75, no. 7, p. 677-682.

Coats, R.R., R.F. Marvin and T.W. Stern, 1965. Reconnaissance of mineral ages of plutons in Elko County, NV, and vicinity. USGS Prof. Paper 525-D, p. 11-15.

Cochran, K.L., 1951. Perlite resources, Meadow Valley Wash area, Clark and Lincoln Counties, NV, Beaver and Millard Counties, UT. Union Pacific Railroad Co. Mem. Rept.

Cole, J.G., 1942. Dolomite near Sloan, NV. Union Pacific Railroad Co. Mem. Rept.

Collinson, J.W., 1968. Permian and Triassic biostratigraphy of the Medicine Range, northeastern NV. Wyoming Geol. Assoc., Earth Sci. Bull., v. 1, no. 4, p. 25-44.

Conway, R.D., 1965. Structure and stratigraphy of a portion of the southern Schell Creek Range, White Pine County, NV. M.S. thesis, Washington Univ.

Coogan, A.H., 1962. Early Pennsylvanian stratigraphy, biostratigraphy, and sedimentation of the Ely Basin, NV. Ph.D. thesis, Univ. of Ill.

_______, 1964. Early Pennsylvanian history of Ely basin NV. Am. Assoc. Pet. Geo. Bull., v. 48, no. 4, p 487-495.

Cook, E.F., 1965 . Stratigraphy of Tertiary volcanic rocks in eastern NV. NV Bur. of Mines Rept. 11.

Cook, K.L., 1966. Rift system in the Basin and Range Province. In Irvine, T.N., ed., The World Rift System: Canada, Geol. Surv. Paper 66-14, p. 246-279.

Cornwall, H.R., 1972. Geology and mineral deposits of southern Nye County, NV. NV Bur. of Mines and Geol., Bull. 77, 49 p.

Cornwall, H.R. and F.J. Kleinhampl, 1961. Geologic map of the Bare Mountain quadrangle, Nye County, NV. USGS Quad. Map. GQ-157.

_______, 1964. Geology of the Bullfrog quadrangle and ore deposits related to the Bullfrog Hills caldera, Nye County, NV and Inyo County, CA. USGS Prof. Paper 454-J, p. J1-J25.

Cornwall, H.R. et al., 1964. Mineral and water resources of NV. NV Bur. of Mines Bull. 65, 314 p.

Cushing, E.M., 1977. The Madison aquifer study - current status. USGS Open File Rept. 77-692, 12 p.

Davies, W.E. and H.E. LeGrand, 1972. Karst of the United States. in: Karst: Important Karst Regions of the Northern Hemisphere, Elsevier, Amsterdam, p. 467-505.

Davis, G.A., 1973. Relations between the Keystone and Red Spring thrust faults, Eastern Spring Mountains, NV. GSA Bull. v. 84, p. 3709-3716.

Decker, R.W., 1962. Geology of the Bull Run quadrangle, Elko County, NV. NV Bur. of Mines Bull. 60, 65 p.

Dechert, C.P., 1967. Bedrock geology of the northern Schell Creek Range, White Pine County, NV. Ph.D. thesis, Washington Univ.

Deiss, C.F., 1952. Dolomite deposit near Sloan, NV. USGS Bull. 973-C.

Denny, C.S. and H. Drewes, 1965. Geology of the Ash Meadows quadrangle, NV-CA. USGS Bull. 1181-L, 56 p.

Divens, D.F., 1957. Geology of the Telegraph Pass area, Diamond Range, White Pine County, NV. M.S. thesis, Univ. of NV.

Dolgoff, A., 1963. Volcanic stratigraphy of the Pahranagat area, Lincoln County, NV, southeastern NV. Geol. Soc. Am. Bull., v. 74, no. 7, p. 875-899.

Dott, R.H., Jr., 1955. Pennsylvanian stratigraphy of Elko and Northern Diamond Ranges, northeastern NV. Am. Assoc. Pet. Geol. Bull., v. 39, no. 11, p. 2211-2306.

Douglass, W.B., Jr. 1960. Geology of the southern Battle Mountains, White Pine County, NV. in IAPG Guidebook, p. 181-185.

Dreessen, R.S., Jr., 1969. Geology of a portion of the Pancake Range, Nye County, NV. M.S. thesis, San Diego State Univ.

Drewes, H., 1958. Structural geology of the southern Snake Range, NV. Geol. Soc. Am. Bull., v. 69, no. 2, p. 221-240.

______, 1967. Geology of the Connors Pass quadrangle, Schell Creek Range, east-central NV. USGS Prof. Paper 557, 93 p.

Drewes, H. and A.R. Palmer, 1957. Cambrian rock of southern Snake Range, NV. Am. Assoc. Pet. Geo. Bull., v. 41, no. 1, p. 104, 120.

Dudley, W.W., Jr., 1967. Hydrogeology and ground-water flow system of the central Ruby Mountains, NV. Ph.D. thesis, Univ. of Illinois.

Dudley, W. W., Jr., and J.D. Larson, 1976. Effect of irrigation pumping on Desert Pupfish habitats in Ash Meadows, Nye County, NV. USGS Prof. Paper 927, 52 p.

Duley, D.H., 1957. Mississippian stratigraphy of the Meadow Valley and Arrow Canyon Ranges, southeastern NV. M.S. thesis, Univ. of CA.

Eakin, T.E., 1960. Ground-water appraisal of Newark Valley, White Pine County, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser. Rept. 1.

_______, 1961a. Ground-water appraisal of Pine Valley, Eureka and Elko Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Recon. Ser. Rept. 2.

_______, 1961b. Ground-water appraisal of Long Valley, White Pine and Elko Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser. Rept. 3.

_______, 1962. Ground-water appraisal of Diamond Valley, Eureka and Elko Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser. Rept. 6.

_______, 1962b. Ground-water appraisal of Independence Valley, western Elko County, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser., Rept. 8.

_______, 1962c. Ground-water appraisal of Ralston and Stonecabin Valleys, Nye County, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser., Rept. 12.

_______, 1962d. Ground-water appraisal of Cave Valley in Lincoln and White Pine Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser., Rept. 13.

_______, 1963a. Ground-water appraisal of Dry Lake and Delamer Valleys, Lincoln County, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser., Rept. 16.

_______, 1963b. Ground-water appraisal of Garden and Coal Valleys, Lincoln and Nye Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser., Rept. 18.

_______, 1963c. Ground-water appraisal of Pahranagat and Pahroc Valleys, Lincoln and Nye Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser., Rept. 21.

_______, 1964. Ground-water appraisal of Coyote Springs and Kane Spring Valleys and Muddy River Springs area, Lincoln and Clark Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser., Rept. 25.

_______, 1966. A regional ground-water system in southeastern NV (abst). Ground Water Jour. 3:1, p. 48.

_______, 1966. A regional interbasin ground-water system in the White River area, southeastern NV. Water Reso. Res. v. 2, no. 2, p. 251-271.

Eakin, T.E., J.L. Hughes and D.O. Moore, 1967. Water-resources appraisal of Steptoe Valley, White Pine and Elko Counties, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser., Rept. 42.

Eakin, T.E. and G.B. Maxey, 1951. Ground water in Ruby Valley, Elko and White Pine Counties, NV. in: Contributions to Hydrology of Eastern NV, State of NV., Water Res. Bull. 12, p. 67-96.

Eakin, T.E. and D.O. Moore, 1964. Uniformity of discharge of Muddy River Springs, southeastern NV and relation to interbasin movement of ground water. USGS Prof. Paper 501D.

Eakin, T.E., D. Price and J.R. Harrill, 1976. Summary appraisals of the nation's ground-water resources - Great Basin region. USGS Prof. Paper 813-G, 37 p.

Easton, W.H., 1960. Permian corals from Nevada and California. Jour. Palentology, v. 34, no. 3, p. 570-583.

Ebanks, W.J., 1965. Structural geology of the Gass Peak area, Las Vegas, NV. Master's thesis, Rice Univ., 56 p.

Eckel, E.B. ed., 1968. Nevada Test Site. GSA Mem. 110.

Ekren, E.B., R.E. Anderson, C.L. Rogers and D.C. Noble, 1971. Geology of northern Nellis Air Force Base bombing and gunnery range, Nye County, NV. USGS Prof. Paper 651, 91 p.

Ekren, E.B. and K.A. Sargent, 1965. Geologic map of the Skull Mountains quadrangle, Nye County NV. USGS Quad. Map GQ-387, scale 1:24,000.

Ely, R.W., 1969. Paleontology and stratigraphy of the Opf unit (Pogonip Group, middle Ordovician) in the Arrow Canyon Range, Clark County, NV. M.S. thesis, Univ. of Illinois.

Evans, J. and L.D. Cress, 1972. Preliminary geologic map of the Schroeder Mountain quadrangle, NV. USGS Misc. Field Studies Map MF-324, scale 1:24,000.

Evans, J.G. and K.B. Ketner, 1971. Geologic map of the Swales Mountain quadrangle and part of the Adobe Summit quadrangle, Elko County, NV. USGS Misc. Geol. Inv. Map I-664, scale 1:24,000.

Everett, D.E. and F.E. Rush, 1966. A brief appraisal of the water resources of Grass and Carico Lake Valleys, Lander and Eureka, Counties, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser., Rept. 37.

Fagan, J.J., 1962. Carboniferous cherts, turbidites, and volcanic rocks in northern Independence Range, NV. Geol. Soc. Am. Bull., v. 73, no. 5, p. 595-612.

Fails, T.G., 1960. Permian stratigraphy at Carlin Canyon, NV. Am. Assoc. Pet. Geo. Bull., v. 44, p. 1692-1703.

Fiero, G.W., Jr., 1968. Regional hydrology Hot Creek - Little Smoky Valley flow system, Nye County, NV. Desert Res. Inst., WRC, Misc. Rept. no. 6.

Fiero, G.W., Jr., and J.R. Illian, 1969. Section B regional ground water flow systems of central NV. Desert Res. Inst., WRC, Misc, Rept. no. 5., 218 p.

Fiero, G.W., Jr., and G.B. Maxey, 1970. Hydrogeology of the Devils' Hole area, Ash Meadows, NV. Desert Res. Inst., WRC, Misc. Rept. no. 9. 30 p.

Findlay, W.F., 1960. Geology of a part of Buck Mountain quadrangle, east-central NV. M.S. thesis, Univ. Southern CA.

Fisher, W.L. and J.E. Sorauf, 1962. Correlation chart of the Permian formations of North America - discussion of the Grand Canyon section. Geol. Soc. Am. Bull., v. 73, no. 5, p. 649-652.

Fitch, D.C., 1969. Geology and ore deposits of the Comet district, Lincoln County, NV. M.S. thesis, Univ. of New Mexico.

Fleck, R.J., 1967. The magnitude, sequence, and style of deformation in southern NV and eastern CA. Ph.D. thesis, CA Univ., Berkeley, 92 p.

________, 1970. Tectonic style, magnitude, and age of deformation in the Sevier orogenic belt in southern NV and eastern CA. GSA Bull. v. 81, p. 1705-1720.

________, 1970b. Age and possible origin of the Las Vegas Valley shear zone, Clark and Nye Counties, NV. GSA Abs. w/prog. (Rocky Mt. Sec.) v. 2, no. 5, p. 333.

________, 1974. Geology of the Charleston Peak and part of the Corn Creek Springs quadrangles, Clark County, NV. NV Bur. Mines Bull.

Flynn, D.B., 1957. Geology of a part of the Dixie Flats quadrangle, Elko County, NV. M.A. thesis, Univ. of Calif., Los Angeles.

Foster, D.I., 1953. Lower Pennsylvanian stratigraphy of the southern Egan Range, NV. M.A. thesis, Columbia Univ.

Freeze, R.A. and P.A. Witherspoon, 1966. Theoretical analysis of regional ground-water flow; 1. Analytical and numerical solutions to the mathematical model. Water Reso. Res. 2:4, p. 641-656.

________, 1966. Theoretical analysis of regional ground-water flow; 2. Effect of water-table configuration and subsurface permeability variation. Water Reso. Res. 3:2, p. 623-634.

Freyne, D.M., 1973. Geology of the Ruby Lake S.E. 7.5 minute quadrangle, White Pine County, NV. M.S. thesis, San Diego.

Fritz, W.H., 1957. Structure and stratigraphy of Telegraph Canyon area, northern Egan Range, east-central, NV. M.S. thesis, Univ. of Washington.

Fritz,, W.H., 1960. Structure and stratigraphy of the northern Egan Range, White Pine County, NV. Ph.D. thesis, Washington Univ.

_______, 1968. Geologic map and sections of the southern Cherry Creek and northern Egan Ranges, White Pine County, NV. NV Bur. of Mines Map 35, MacKay School of Mines, Univ. of NV.

Frost, S.H., 1963. The stratigraphy and paleontology of the Piute Formation, Arrow Canyon Range, NV. M.S. thesis, Univ. of Illinois.

Fulton, J.A. and A.M. Smith, 1932. Nonmetallic minerals in NV. NV Univ. Bull., v. 26, no. 7, NV Bur. Mines and MacKay School of Mines Bull. no. 17.

Gaal, R., 1958. Geology of the central portion of the Green Springs quadrangle, NV. Univ. Southern Calif., Los Angeles, Master's thesis.

Gale, H.S., 1921. The Calville Wash colemanite deposit, Clark County, NV. Eng. Mining Jour., v. 112, no. 14, p. 524-530.

Gallagher, M.J., 1955. Nevada mines, mills, and smelters in operation as of July 1, 1954. Rept. of the Inspector of Mines, Carson City, NV.

Gans, W.R., 1970. The detailed stratigraphy of the Goodsprings Dolomite southeastern Nevada - California. Ph.D. thesis, Rice Univ., 87 p.

Garber, M.S. and F.C. Koopman. Methods of measuring water levels in deep wells. Techniques of Water-Resources investigations of the USGS Book 8, Chpt. Al, 23 p.

Garside, L.J., 1968. Geology of the Bishop Creek area, Elko County, NV. M.S. thesis, Univ. of NV.

Gianella, V.R. and E. Callaghan, 1934. The earthquake of 12/20/1932, at Cedar Mountain, NV and its bearing on the genesis of Basin Range structure. Jour. Geol., v. 42, p. 1-22.

Gibbons, A.B., E.N. Hinrichs, W.R. Hansen and R.W. Lemke, 1963. Geology of the Rainer Mesa quadrangle, Nye County, NV. USGS Geol. Quad. Map GQ-215.

Gilbert, C.K., 1895. Report on the geology of portions of Nevada, Utah, California, and Arizona, p. 1-187, pt I, in U.S. Geographical and Geological Surveys West of the 100th Meridian, v. 3, 681 p.

Gilluly, J. and H. Masursky, 1965. Geology of the Cortez quadrangle, NV. USGS Bull. 1175, 117 p.

Glancy, P.A., 1968. Water-resources appraisal of Butte Valley, Elko and White Pine Counties, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser. Rept. 49.

_______, 1968. Water-resources appraisal of Mesquite-Ivanpah Valley Area, Nevada and California. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser. Rept. 46.

Glancy, P.S. and A.S. VanDenburg. Water-resources appraisal of the lower Virgin River Valley area, Nevada, Arizona and Utah. NV Dept. of Cons. and Nat. Reso., Water Recon. Ser. Rept. 51.

Glock, W.S., 1929. Geology of the east-central part of the Spring Mountain Range, NV. Am. Jour. Sci., v. 217, p. 326-341.

Granger, A.E., M.M. Bell, G.C. Simmons, and F. Lee, 1957. Geology and mineral resources of Elko County, NV. NV Bur. of Mines Bull. 54.

Greene, J.M., 1953. Paleozoic stratigraphy of Clear Creek Canyon, Monitor Range, Nye County, NV. M.A. thesis, Columbia Univ.

Griffith, L.S. The Carboniferous geology of the Pahranagat Range. M.A. thesis, Rice Univ.

Grove, D.B., M. Tubin, B.B. Hanshaw, and W.A. Beetem, 1969. Carbon 14 dates of ground water from a Paleozoic carbonate aquifer, south central Nevada. USGS Prof. Paper 650C, C215-C218.

Gumper, F. and C.H. Scholz, 1971. Nevada seismic zone. Seismol. Soc. Am. Bull., v. 61, p. 1413-1432.

Hackbarth, D.A., 1978. Application of the drill-stem test to hydrogeology. Ground Water v. 16, no. 1, p. 5-11.

Hague, A. 1883. Abstract of the geology of the report on the Eureka district, NV. USGS 3rd Ann. Rept., p. 237-290.

_______, 1892. Geology of the Eureka district, NV. USGS Mon. 20.

Hale, F.A., Jr., 1918. Manganese deposits of Clark County, NV. Eng. Mining Jour., v. 105, p. 775-777.

Halley, R.B., 1974. Repetitive carbonate bank development and subsequent terrigeneous inundation; Cambrian Carrera Formation, southern Great Basin. Ph.D. thesis, New York State Univ., Stony Brook.

Hamill, G.S., IV, 1966. Structure and stratigraphy of the Mount Shader quadrangle, Nye County, Nevada-Inyo County, California. Ph.D. thesis, Rice Univ., 83 p.

Hansen, M.W., 1975. Carbonate microfacies of the Monte Cristo Group (Mississippian), Arrow Canyon Range, Clark County, NV. Ph.D. thesis, Univ. of Illinois.

Harlow, G.R., 1956. The stratigraphy and structure of the Spruce Mountain area, Elko County, NV. M.S. thesis, Univ. of Washington.

Harrill, J.R., 1971. Water-resources appraisal of the Pilot Creek Valley area, Elko and White Pine Counties, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser. Rept. 56.

Haynes, V.C., 1967. Quaternary geology of the Tule Springs area, Clark County, in Pleistocene studies in southern Nevada, Nev. State Mus. Anthropological Papers, No. 13, p. 17-104.

Hazzard, J.C. and J.F. Mason, 1953. The Goodsprings Dolomite at Goodsprings, NV. Am. Jour. Sci., v. 251, no. 9, p. 643-655.

Heath, C.P.M., 1965. Microfacies of the lower Bird Spring Group (Pennsylvanian-Permian), Arrow Canyon Range, Clark County, NV. Ph.D. thesis, Univ. of Illinois.

Herak, M. and V.T. Stringfield, 1972. Conclusions. in Karst: Important Karst regions of the northern hemisphere. Elsevier, Amsterdam, p. 507-518.

Hess, J.W., 1974. Hydrochemical investigations of the central Kentucky Karst aquifers system. Ph.D. thesis, Penn. State Univ.

Hess, J.W. and W. B. White, 1974. Hydrograph analysis of carbonate aquifers. Inst. for Res. on Land and Water Reso., Penn. State Univ., Res. Publ, no. 83, 63 p.

Hewett, D.F., 1923. Carnotite in southern NV. Eng. Mining Jour. v. 115, no. 5, p. 232-235.

_______, 1931. Geology and ore deposits of the Goodsprings quadrangle, NV. USGS Prof. Paper 162, 172 p.

_______, 1956. Geology and mineral resources of the Ivanpah quadrangle, California and Nevada. USGS Prof. Paper 275, 172 p.

_______, 1955. Structural features of the Mojave Desert region. GSA Spec. Paper 62, p. 377-390.

Hewett, D.F. and B.N. Webber, 1931. Bedded deposits of manganese oxides near Las Vegas, NV. NV Univ. Bull., v. 25, no. 6, NV Bur. Mines and MacKay School of Mines Bull. 13.

Hill, J.M., 1916. Notes on some mining districts in eastern Nevada. USGS Bull. 648.

Hilpman, P.L., 1959. Geology of the Easy Ridge area, White Pine County, NV. M.S. thesis, Univ. of Kansas.

Hinrichs, E.N., 1968. Geologic map of the Camp Desert Rock quadrangle, Nye County, NV. USGS Quad. Map GQ-726, scale 1:24,000.

Hinrichs, E.N. and E.J. McKay, 1965. Geologic map of the Plutonium Valley quadrangle, Nye and Lincoln Counties, NV. USGS Geol. Quad. Map GQ-384.

Hinrichs, E.N. and P.P. Orkild, 1961. Eight members of the Oak Spring Formation, Nevada Test Site and vicinity, Nye and Lincoln Counties, NV. USGS Prof. Paper 424-D, Art. 327, p. 96-103.

Hintze, L.F., 1950. Ordovician stratigraphy from central Utah to central Nevada. Ph.D. thesis, Columbia Univ.

Hintze, L.F., 1951. Lower Ordovician detailed stratigraphic section for western Utah. UT Geol. and Min. Survey Bull. 39.

_______, 1952. Lower Ordovician trilobites from western Utah and eastern Nv. UT Geol. and Min. Survey Bull. 48.

_______, 1960. Ordovician of the Utah-Nevada Great Basin. in IAPG Guidebook, p. 59-62.

Holland, B.D., 1956. Geology of the Bull Fork area, White Pine and Nye Counties, NV. M.S. thesis, Univ. of Kansas.

Hood, J.W. and F.E. Rush, 1965. Water-resources appraisal of the Snake Valley area, Utah and Nevada. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser. Rept. 34.

Hope, R.A., 1972. Geologic map of the Spruce Mountain quadrangle, Elko County, NV. USGS Quad. Map GQ-942, scale 1:62,500.

Hose, R.K. and M.C. Blake, Jr., 1970. Geologic map of White Pine County, NV. USGS Open-file map, scale 1:150,000.

Hose, R.K., M.C. Blake, Jr., and R.M. Smith. Geology and mineral resources of White Pine County, NV. NV Bur. of Mines, Bull. 85, 105 p.

Houser, F.N. and F.G. Poole, 1960. Preliminary geologic map of the Climax Stock and vicinity, Nye County NV. Misc. Geol. Invest., Map 14328.

Howard, K.A. and J.F. Smith, unpub. data, 1971. Geologic map of the Lee quadrangle, Elko County, NV. scale 1:62,500.

Hughes, J.L., 1966. Some aspects of the hydrogeology of the Spring Mountains and Pahrump Valley, Nevada, and environs as determined by spring evaluation. M.S. thesis, Univ. of NV, 116 p.

Humphrey, F.L., 1945. Geology of the Groom district, Lincoln County, NV. E.M. thesis, Univ. of NV.

_______, 1960. Geology of the White Pine Mining District, White Pine County, Nevada. NV Bur. Mines Bull. 57, 119 p.

Hunt, C.B., V.E. McKelvey and J.H. Wiese, 1942. Three Kids Manganese District, Clark County, NV. USGS Bull. 936-L, p. 297-319.

Hunt, C.S. and T.W. Robinson, 1960. Possible interbasin circulation of ground water in the southern part of the Great Basin. USGS Paper 400B, p. B273-B274.

Huttrer, G.W., 1963. Structure and stratigraphy of the central Grant Range, NV. M.S. thesis, Washington Univ.

Hyde, J.H., 1963. Structure and stratigraphy of the north-central Grant Range, NV. M.S. thesis, Washington, Univ.

Ivosevic, S.W., 1976. Geology and ore deposits of the Johnnie District, Nye County, NV. M.S. thesis, Univ. of NV, Reno.

Jacobson, R.L. and D. Langmuir, 1970. The chemical history of some spring waters in carbonate rocks. Groundwater 8:1-7.

Johnson, C.A., (in preparation). Environmental controls on occurrence and chemistry of ground water in a carbonate terrain of eastern Nevada.

Johnson, J.G., 1959. Geology of the northern Simpson Park Range, Eureka County, NV. Ph.D. thesis, Calif. Univ., Los Angeles.

Johnson, J.G., 1962a. Brachiopod faunas of the Nevada Formation (Devonian) in central NV. Jour. Paleontology, v. 36, no. 1, p. 165-169.

_______, 1962b. Lower Devoniann-middle Devonian boundary in central NV. Am. Assoc. Pet. Geol. Bull., v. 46, no.4, p. 542-546.

Johnson, J.G. and A. Reso, 1964. Probable ludlovian brachiopods from the Sevy Dolomite of NV. Jour. Paleontology, v. 38, no. 1, p. 74-84.

Johnson, M.S. and D.E. Hibbard, 1957. A geological survey of the Atomic Energy Commission Nevada Proving Grounds area, Nye County, NV. USGS Bull. 1021-K.

Kay, M. and J.P. Crawford, 1964. Paleozoic facies from the miogeosynclinal to the eugeosynclinal belt in thrust slices, central Nevada. Geol. Soc. Am. Bull., v. 75, no. 5, p. 425-454.

Kellogg, H.E., 1960. Geology of the southern Egan Range, NV. in IAPG Guidebook, p. 189-197.

_______, 1963. Paleozoic stratigraphy of the southern Egan Range, NV. Geol. Soc. Am. Bull., v. 74, no. 6, p. 685-708.

_______, 1964. Cenozoic stratigraphy and structure of the southern Egan Range, NV. Geol. Soc. Am. Bull., v. 75, no. 10, p. 949-968 (pl. 1).

Kendall, G.W., 1975. Some aspects of lower and middle Devonian stratigraphy in Eureka County, NV. M.S. thesis, Oregon State Univ.

Kennerley, J.B., 1960. An environmental and stratigraphic study of the Silurian system, Arrow Canyon Range, NV. M.S. thesis, Univ. of Illinois.

Ketner, K.B. and J.F. Smith, Jr., 1963. Geology of the Railroad Mining District, Elko County, NV. USGS Bull. 1162-B.

Keys, W.S., 1955. The geology of the Mary Ellen mine, Hamilton District, White Pine County, NV. M.A. thesis, Univ. of Calif., Los Angeles.

King, P.B., 1960. The anatomy and habitat of low-angle thrust faults. Am. Jour. Sci., v. 258-A, p. 115-125.

King, W.H., J.H. Soule and R.R. Trencove, 1949. Investigation of Virgin River manganese deposit, Clark County, NV. U.S. Bur. Mines Rept. Inves. 4471.

King, W. H. and R.R. Trencove, 1950. Investigation of the Fannie Ryan and Boulder City manganese deposits, Clark County, NV. U.S. Bur. Mines Rept. Inves. 4712.

Kirkpatrick, D. H., 1960. Structure and stratigraphy of the northern portion of the Great Range, east-central, NV. in IAPG 11th Guidebook, p. 186-188.

Kistler, R.W. and R. Willden, 1969. Age of thrusting in the Ruby Mountains, NV. GSA Abs, w/prog. for 1969, pt. 5 (Rocky Mountain Sec.), p. 40-41.

Kleinhample, F.J. and J.I. Ziony, 1967. Preliminary geologic map of northern Nye County, NV. USGS Open-file map.

Knight, R.L., 1956. Permian fusulines from NV. Jour. Paleontology, v. 30, no. 4, p. 773-792.

Knopf, A., 1915. A gold-platinum palladium lode in southern Nevada. USGS Bull. 620-A, p. 1-18.

Knorr, J.H., 1967. Permian studies of Nevada (Clark, White Pine, and Elko Counties). M.S. thesis, Univ. of Iowa.

Konikow, L.F., 1978. Hydrogeologic considerations for an interstate ground-water compact on the Madison aquifer, northern Great Plains. USGS Open-file rept. 78-138, 8 p.

Kovinick, M.G., 1956. Geology of the Trout Creek area, Elko and Eureka Counties, NV. M.A. thesis, Univ. of Calif., Los Angeles.

Lamport, M.B., 1969. Geology of the southern half of the West Range, Lincoln County, NV. B.S., Univ. of Illinois.

Lane, B. 1960. The Ely Limestone in the vicinity of Moorman Ranch, NV. in IAPG Guidebook, p. 114-116.

Langenheim, R.L., Jr., F.T. Barr, S.E. Shank, L.J. Stensaas, and E.C. Wilson, 1960. Preliminary report on the geology of the Ely No. 3 quadrangle, White Pine, NV. Intermountain Assoc. Petroleum Geologists, p. 148-157.

Langenheim, R.L., 1956. Lower Mississippian stratigraphic units in southern Nevada (abs.). GSA Bull. v. 67, no. 12, p. 1773.

______, 1960. Early and middle Mississippian stratigraphy of the Ely area. Intermountain Assoc. Petroleum Geologists, p. 72-80.

______, 1960. The Pilot Shale, the West Range Limestone, and the Devonian-Mississippian boundary in eastern NV. Illinois Acad. Sci. Trans., v. 53, no. 3-4, p. 122-131.

Langenheim, R.L., Jr., 1962. Nomenclature of the late Mississippian White Pine Shale and associated rocks in NV. Illinois Acad. Sci. Trans., v. 55, no. 2, p. 133-145.

_______, 1963, Mississippian stratigraphy in southwestern Utah and adjacent parts of Nevada and Arizona, in Guidebook to the geology of southwestern Utah. Intermountain Assoc. Pet. Geol., 12th Ann. Field Conf., p. 30-41.

Langenheim, R.L., Jr., W.B. Brackin, Jr., J.W. Granath, and T.C. Labotka, 1971. Geology of the Bristol Pass region and the Silverhorn and Fairview Mining Districts, Lincoln County, NV. Wyoming Geol. Assoc. Earth Sci. Bull., Spet. 1971, v. 4, no. 3, p. 59-76 (fig.2).

Langenheim, R.L., Jr., B.W. Carss, J.B. Kennerly, V.A. McCutcheon, and R.H. Waines, 1962. Paleozoic section in Arrow Canyon Range, Clark County, NV. AAPG Bull. v. 46, p. 592-609.

Langenheim, R.L., Jr., and C.W. Collinson, 1963. Upper Devonian Crystal Pass Limestone of southern Nevada (abs.). Geol. Soc. Am. Spec. Paper 73, p. 45.

Langenheim, R.L., Jr., J.D. Hill and R.H. Waines, 1960. Devonian stratigraphy of the Ely Area. Intermountain Assoc. of Pet. Geol., p. 63-71.

Langenheim, R.L., Jr., M.B. Lamport, and J.M. Winter, 1969. Geology, stratigraphy and structure of the West Range, Lincoln County, NV. Wyoming Geol. Assoc. Earth Sci. Bull., Sept. 1969, V. 2, no. 3, p. 27-36 (fig.2).

Langenheim, R.L., E.R. Larson, and Eastern NV Geol. Soc., 1973. Correlation of Great Basin stratigraphic units. NV Bur. of Mines and Geo. Bull 72, MacKay School of Mines, Univ. of NV, Reno.

Langenheim, V.A., 1957. Pennsylvanian and Permian paleontology and stratigraphy of Arrow Canyon, Arrow Canyon Range, Clark County, NV. M.A. thesis, Univ. of Calif.

Langmuir, D., 1971. The geochemistry of some carbonate groundwaters in central Pennsylvania. Geochim. Cosmochim, Act. 35:1023-1045.

Larson, E.R., and J.F. Riva, 1963. Preliminary geologic map and sections of the Diamond Springs quadrangle, NV. NV Bur. Mines Map 20, scale 1:62,500.

Lattman, L.H. and R. R. Patizek, 1964. Relationship between fracture traces and the occurrence of groundwater in carbonate rocks: Jour Hydrology, 2: p. 73-96.

Ledbetter, M.T., 1970. A Pennsylvanian- Permian shelf to Craton Transition, Azure Ridge, Clark County, NV. M.S. thesis, Memphis State Univ.

Lee, D.E., R.F. Marvin, T.W. Stern, and Z.E. Peterman, 1970. Modification of K-Ar ages by tertiary thrusting in the Snake Range, White Pine County, NV. USGS Prof. Paper 700D, p. 92-102.

Lee, D.E., T.W. Stern, R.E. Mays and R.E. Van Loenen, 1968. Accessory zircon from granitoid rocks of the Mount Wheeler mine area, NV. USGS Prof. Paper 600D, p. 197-203.

Leighton, F.B., 1954. Origin of vermiculite deposits, southern Virgin Mountain, NV (abs.). Econ. Geology v. 49, no. 7, p. 809.

Lincoln, F.C., 1923. Mining districts and mineral resources of NV. NV Newsletter Pub. Co., Reno, NV.

Lindh, A.G., 1973. Nevada focal mechanisms and regional stress fields. AGU Trans., v. 54, p. 1133.

Lintz, J., Jr., 1957. Nevada oil and gas drilling data, 1906-1953. NV Bur. Mines Bull. 52.

Lipman, P.W., and E.J. McKay, 1965. Geologic map of the Tonopah Spring SW quadrangle, Nye County, NV. USGS Quad. Map GQ-439, scale 1:24,000.

Livingston, J.L., 1964. Stratigraphic and structural relations in a portion of the northwest Spring Mountains, NV. M.S. thesis, Rice Univ., 35 p.

Lloyd, G.P., II, 1959. Geology of the north end of White River Valley, White Pine County, NV. M.A. thesis, Calif. Univ. Los Angeles.

Loeltz, O.J., 1960. Sources of water issuing from springs in Ash Meadows Valley, Nye County, NV (abs.). GSA Bull. 72:2, p. 1917-1918.

Loeltz, O.J. and G.T. Malmberg, 1961. The ground-water situation in Nevada. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. - Information Series, Rept. 1.

Long, J.F., 1973. Stratigraphy and depositional environments of shoal water carbonate rocks in the Fish Creek Range, central Nevada. M.S. thesis, Univ. of Calif. Riverside.

Longwell, C.R., 1921. Geology of the Muddy Mountains, Nevada, with a section to the Grand Wash Cliffs in western Arizona. Am. Jour. Sci., 5th Ser., v. 1, p. 39-62.

_______, 1922, Muddy Mountain overthrust in southeastern Nevada. Jour. Geol., v. 30, p. 63-72.

_______, 1925. The pre-Triassic unconformity in southern Nevada. Am. Jour. Sci., 5th ser., v. 10, p. 93-106.

_______, 1926. Structural studies in southern Nevada and western Arizona. GSA Bull., v. 37, p. 551-584.

_______, 1928. Geology of the Muddy Mountains, Nevada with a section through the Virgin Range to the Grand Wash Cliffs, Arizona. USGS Bull 798.

_______, 1930. Faulted fans west of the Sheep Range, southern Nevada. Am. Jour. Sci., 5th Ser., v. 20, p. 1-13.

Longwell, C.R., 1936. Geology of the Boulder Reservoir floor, Arizona-Nevada. GSA Bull. v. 47, no. 9, p. 1393-1476.

_______, 1945b. Low-angle normal faults in the Basin and Range Province. AGU Trans., v. 26, pt. 1, p. 107-118.

_______, 1949. Structure of the northern Muddy Mountain area, Nevada. GSA Bull. v. 60, p. 923-967.

_______, 1952. Structure of the Muddy Mountains, NV. Utah Geol. and Mineralogical Survey Guidebook no. 7, p. 109-114.

_______, 1952a. Basin and Range geology west of St. George Basin, Utah. in Thune, H.W., ed., Cedar City, Utah to Las Vegas, NV. Utah Geol. Soc. Guidebook to the Geology of UT no. 7, p. 27-42.

_______, 1960. Possible explanation of diverse structural patterns in southern NV. Am. Jour. Sci. V. 258A, p. 192-203.

_______, 1962. Restudy of the Arrowhead fault, Muddy Mountains, NV. USGS Prof. Paper 450-D, Art. 144, p. D82-D85.

_______, 1973. Structural studies in southern Nevada and western Arizona. A correction. GSA Bull., v. 84, p. 3717-3720.

_______, 1974. Measure and date of movement on Las Vegas Valley shear zone, Clark County, NV. GSA Bull. v. 85, p. 985-990.

Longwell, C.R. and C.O. Dunbar, 1936. Problems of Pennsylvanian Permian boundary in southern NV. AAPG Bull. v. 20, no. 9, p. 1198-1207.

Longwell, C.R., E.H. Pampeyan, B. Bowyer and R.J. Roberts, 1965. Geology and mineral deposits of Clark County, NV. NV Bur. Mines Bull. 62.

Lovejoy, D.W., 1959. Overthrust Ordovician and the Nannie's Peak intrusive, Lone Mountain, Elko County, NV. Geol. Soc. Am. Bull., v. 70, p. 539-563.

Lumsden, D.N., 1965. Microfacies of the middle Bird Spring Group (Pennsylvanian-permian), Arrow Canyon Range, Clark County, NV. Ph.D. thesis, Univ. of Illinois.

Lumsden, W.W., 1964. Geology of the southern White Pine Range and northern Horse Range, Nye and White Pine Counties, NV. Ph.D. thesis, Calif. Univ., Los Angeles.

Lutsey, I.A., 1978. Bibliography of graduate thesies on Nevada Geology to 1976. NV Bur. Mines and Geo. Rept. 31.

MacDiamid, R.A., 1959. Geology and ore deposits of the Bristol Silver Mine, Pioche, NV. Ph.D. thesis, Stanford Univ.

Mackin, J.H., 1960. Structural significance of Tertiary volcanic rocks in southwestern Utah. Am. Jour. Sci., v. 258. no. 2, p. 81-131.

Malmberg, G.T., 1961. A summary of the hydrology of the Las Vegas ground-water basin, NV, with special reference to available supply. USGS Water Resources Bull. 18.

_______, 1967. Hydrology of the valley-fill and carbonate-rock reservoirs, Pahrump Valley, Nevada and California. USGS Water Supply Paper 1832, p. 47.

Malmberg, G.T. and T.E. Eakin, 1962. Ground-water appraisal of Sarcobatus Flat and Oasis Valley, Nye and Esmeralda Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. Recon. Ser. Rept. 10.

Mapco, 1978. Oil and gas development. Maps of Nevada. Denver, CO.

Marks, J.W., 1966. Elemental composition and its stratigraphic significance in Whiterockian to Givetian rocks of the Arrow Canyon Range, Clark County, NV. M.S. thesis, Univ. of Illinois.

Mason, J.F., 1935. Paleontology and stratigraphy of the lower part of the Cambrian section of the Highland Range, NV. M.A. thesis, Univ. of Southern Calif.

Matti, J.C., 1971. Physical stratigraphy and conodont biostratigraphy of lower Devonian Limestone, Copenhagen Canyon, NV. M.S. thesis, Univ. of Calif., Riverside.

Maxey, G.B. and T.E. Eakin, 1949. Ground water in White River Valley, White Pine, Nye and Lincoln Counties, NV. USGS Water Reso. Bull. 8.

_______, 1948. Geology and water resources of Las Vegas, Pahrump and Indian Springs Valleys, Clark and Nye Counties, State of NV, Office of the State Engineer, Water Reso. Bull. no. 5.

Maxey, G.B. and C.H. Jameson, 1964. Well data in Las Vegas and Indian Spring Valleys, NV. USGS Water Reso. Bull. 4.

Maxey, G.B. and M.D. Mifflin, 1966. Occurrence and movement of ground water in carbonate rocks of Nevada. Natl. Speleo. Soc. Bull. 28:3, p. 141-157.

Maxey, G.B. and T.W. Robinson, 1947. Ground water in Las Vegas, Pahrump, and Indian Springs Valleys, NV (a summary). USGS Water Reso. Bull. 6.

McCarthy, R.J., 1974. Geology of the southern Maverick Springs Range, White Pine County, NV. M.S. thesis, Calif. State Univ., San Diego.

McCleary, J.R., 1974. Geology of the Carbon Ridge area, Eureka County, NV with emphasis on the Diamond Peak Formation. M.S. thesis, Univ. of NV, Reno.

McDougall, D.S., 1973. Carbonate microfacies of the upper Monte Cristo Limestone (Mississippian) and the lower Bird Spring (Pennsylvanian) Group of Mountain Springs, Clark County, NV. M.S. thesis, Univ. of Southern Calif.

McDowell, F.W., and J.L. Kulp, 1967. Age of intrusion and ore deposition in the Robinson Mining District of NV. Econ. Geol., v. 62, p. 905-909.

McFarlane, J.J., 1955. Silurian strata of the eastern Great Basin, M.S. thesis, Brigham Young Univ.

McGuinness, C.L., 1963. The role of ground water in the national water situation. USGS Water Supply Paper 1800, 1121 p.

McJannett, G.S. and E.W. Clark, 1960. Drilling of the Meridian, Hyden Creek and Summit Springs structures. in IAPG, p. 248-250.

McKay, E.J. and K.A. Sargent, 1970. Geologic map of the Lathrop Wells quadrangle, Nye County, NV. USGS Quad. Map GQ-883, scale 1:24,000.

McKay, E.J. and W.P. Williams, 1964. Geologic map of the Jackass Flats, Nye County NV. USGS Quad. Map GQ-368, scale 1:24,000.

McKee, E.D., 1938. The environment and history of the Toroweap and Kaibab Formations of northern Arizona and southern Utah. Carnegie Inst. Wash. Pub. 492.

McKee, E.J., 1972. Preliminary geologic map of the Wildcat Peak quadrangle and the western part of the Dianas Punch Bowl quadrangle, NV. USGS Misc. Field Studies Map MF-337. scale 1:62,500.

McKee, E.D. et al., 1956. Paleotectonic maps of the Jurassic system. USGS Misc. Geol. Invest., Map I-175..

_______, 1959. Paleotectonic maps of the Triassic system. USGS Misc. Geol. Invest., Map I-300.

McKelvey, V.E., J.H. Wiese, and V.H. Johnson, 1949. Preliminary report on the bedded manganese of Lake Mead region, Nevada and Arizona. USGS Bull. 948-D.

McLane, A., 1972. Written communication.

_______, 1974. A bibliography of Nevada caves, Desert Res. Inst., WRC, Misc. Rept. 16, 99 p.

McNair, A.H., 1951. Paleozoic stratigraphy of part of north-western Arizona. Am. Assoc. Pet. Geol. Bull., v. 35, no. 3, p. 503-541.

McNair, A.H., 1952. Summary of the pre-Coconino stratigraphy of southwestern Utah, northwestern Arizona, and southeastern Nevada. in Thune, H.W., ed., Cedar City, Utah, to Las Vegas, Nevada. Utah Geol. Soc. Guidebook to the Geology of Utah, no. 7, p. 45-51.

Merriam, C.W., 1940. Devonian stratigraphy and paleontology of the Roberts Mountain region, NV. GSA Spec. Paper 25.

_______, 1963. Paleozoic rocks of Antelope Valley, Eureka and Nye Counties, NV. USGS Prof. Paper 423, 67 p.

Merriam, C.W. and C.A. Anderson, 1942. Reconnaissance survey of the Roberts Mountains, NV. Geol. Soc. Am. Bull., v. 53, no. 12, pt. 1, p. 1675-1728.

Merrill, J.D., 1960. Geology of the lower part of Buck Mountain quadrangle. Master's thesis, Univ. Southern Calif., Los Angeles.

Micklin, R. F. Pennsylvania paleontology and stratigraphy at Tungsten Gap north, Arrow Canyon Range, Clark County, NV. B.S., Univ. of Illinois.

Miffler, L.J.P., 1964. Geology of the Frenchie Creek quadrangle, north-central Nevada. USGS Bull. 1179, 96 p.

Mifflin, M.D., 1968. Delineation of ground-water flow systems in Nevada. Desert Res. Inst., WRC, Tech. Rept. Ser. H-W 4.

Miller, J.C., 1945. Geologic reconnaissance of Arden area, Clark County. USGS Open-file Rept.

Minnick, E.P., 1975. Stratigraphy and structure of the Vinini Formation, Tyrone Creek area, Eureka County, NV. M.S. thesis, Ohio Univ.

Misch, P., 1960. Regional structural reconnaissance in central-northeast Nevada and some adjacent areas: Observations and interpretations. Intermountain Assoc. of Pet. Geol. p. 17-42.

Misch, P. and J.C. Hazzard, 1962. Stratigraphy and metamorphism of late Precambrian rocks in central northeastern Nevada and adjacent Utah. AAPG Bull. v. 46, p. 289-343.

Missallati, A.A., 1973. Geology and ore deposits of the Mount Hope Mining District, Eureka County, NV. PH.D. thesis, Stanford Univ.

Mollazal, Y., 1961. Petrology and petrography of Ely Limestone in part of eastern Great Basin. M.S. thesis, Brigham Young Univ.

Moore, D.O. and T.E. Eakin, 1968. Water-resources appraisal of the Snake River Basin in Nevada. NV Dept. of Cons. and Nat. Reso., Water Reso. - Recon. Ser. Rept. 48.

Moore, J.G., 1960. Curvature of normal faults in the Basin and Range Province of the western United States. USGS Prof. Paper 400-B, p. B409-B411.

Moore, J.N., 1976. The lower Cambrian Poleta Formation; a tidally dominated open coastal and carbonate bank depositional complex, western Great Basin. Ph.D. thesis, Univ. of Calif., Los Angeles.

Moore, R.T., 1972. Geology of the Virgin and Beavertown Mountains, Arizona. Arizona Bur. of Mines, Bull. 186, 65 p.

Moores, E.M., 1963. Geology of the Currant area, Nye County, NV. Ph.D. thesis, Princeton Univ., Princeton, N.J.

Moores, E.M., R.B. Scott and W.W. Lumsden, 1968. Tertiary tectonics of the White Pine-Grant Range region, east-central Nevada and some regional implications. Geol. Soc. Am. Bull., v. 79, p. 1703-1726.

Morgan, J.R., 1968. Northern part of the south Virgin Mountains, Clark County, NV. M.S. thesis, New Mexico Univ., Albuquerque, 103 p.

Muffler, L.P.J., 1964. Geology of the Fenchie Creek quadrangle, north-central Nevada. USGS Bull. 1179, 99 p.

Murphy, T.D., 1954. Silica resources of Clark County, NV. NV Bur. Mines Bull. 55.

Nadjmabadi, S., 1967. Paleo-environment of the Guilmitte Limestone (Devonian) near Wendover, NV. M.S. thesis, Brigham Young Univ.

Naff, R.L., 1973. Hydrogeology of the southern part of Amargosa Desert in Nevada. unpub. M.S. thesis, Univ. of NV, Reno, 207 p.

Naff, R.L., G.B. Maxey and R.F. Kaufman, 1974. Interbasin ground-water flow in southern Nevada. NV Bur. Mines and Geology Rept. 20, 28 p.

Nahana, R., 1961. Geology of the northeast quarter of the Treasure Hill quadrangle, NV. Master's thesis, Univ. Southern Calif.

National Academy of Sciences, 1976. Water in carbonate rocks. U.S. progress in perspective, 36 p.

Neder, I.R., 1967. Geology of a central part of the Bird Spring Range, Clark County, NV. M.A. thesis, Univ. of Calif., Los Angeles.

Needham, A.B., J.H. Soule, and R.R. Trencove, 1950. Investigation of the Great Eastern Nickel Deposit, Clark County, NV. U.S. Bur. Mines, Rept. Inves. 4679.

Nelson, R.B., 1956. The stratigraphy and structure of the region surrounding Currie, Elko County NV. Master's thesis, Washington Univ.

______, 1959. The stratigraphy and structure of the northern-most part of the northern Snake Range and Kern Mountains in eastern Nevada and the southern Deep Creek Range in western Utah. Ph.D. thesis, Univ. of Washington.

______, 1966. Structural development of northernmost Snake Range, Kern Mountains, and Deep Creek Range, Nevada and Utah. Am. Assoc. Pet. Geol. Bull., v. 50, no. 5, p. 921-951.

______, 1969. Relations and history of structures in a sedimentary succession with deeper metamorphic structure, eastern Great Basin. AAPG Bull., v. 53, p. 307-339.

Nevada, State of, 1972. Hydrologic atlas. 22 maps.

Nobel, D.C., R.E. Anderson, E.B. Ekren and J.T. O'Connor, 1964. Thirsty Canyon Tuff of Nye and Esmeralda Counties, NV. USGS Prof. Paper 475-D, Art. 126, p. D24-D27.

Noble, L.F., 1922. Colemanite in Clark County, NV. USGS Bull. 735-B, p. 23-39.

Nolan, T.B., 1924. Notes on the stratigraphy and structure of the northwest portion of the Spring Mountains, NV. Ph.D. thesis, Yale Univ.

_______, 1929. Notes on the stratigraphy and structure of the northwest portion of the Spring Mountains, NV. Am. Jour. Sci., v. 217, p. 461-472.

_______, 1962. The Eureka Mining District, NV. USGS Prof. Paper 406, 78 p.

Nolan, T.B., C.W. Merriam, and M.C. Blake, Jr., 1974. Geologic map of the Pinto Summit quadrangle, NV. USGS Misc. Geol. Inv. Map I-793.

Nolan, T.B., C.W. Merriam and D.A. Brew, 1971. Geologic map of the Eureka quadrangle, Eureka and White Pine Counties, NV. USGS Geo. Quad. Map I-612, scale 1:31,680.

Nolan, T.B., C.W. Merriam and J.S. Williams, 1956. The stratigraphic section in the vicinity of Eureka, NV. USGS Prof. Paper 276.

Nowak, F.J., 1972. Microfacies of the upper Bird Spring Group, Arrow Canyon Range, Clark County, NV. Ph.D. thesis, Univ. of Illinois.

O'Brien, K.G., 1963. Stratigraphy and paleontology of the Silverhorn Dolomite of Dutch John Mountain, Lincoln County, NV. M.S. thesis, Univ. of Illinois.

Olmore, S.D., 1971. Style and evolution of thrusts in the region of the Mormon Mountains, NV. Ph.D. thesis, Utah Univ.

Olsen, D.R., 1960. Geology and mineralogy of the Delno Mining District and vicinity, Elko County, NV. Ph.D. thesis, Univ. of Utah.

O'Neill, J.M., 1968. Geology of the southern Pilot Range, Elko County, NV, and Box Elder and Tooele Counties, Utah. Master's thesis, New Mexico Univ.

Orkild, P.P., 1963. Geologic map of the Tippipah Spring quadrangle, Nye County, NV. USGS Quad. Map GQ-213.

Osmond, J.C., 1954. Dolomites in Silurian and Devonian of east-central Nevada. Ph.D. thesis, Columbia Univ.

_______, 1962. Stratigraphy of Devonian Sevy Dolomite in Utah and NV. Am. Assoc. Pet. Geo. Bull., v. 46, no.11, p. 2033-2056.

Ottooni, M.A., 1958. Upper Ordovician dolomite sequence of the southern Egan Range, NV. M.A. thesis, Columbia Univ.

Oversby, B.S., 1969. An early Antlerian Mississippian orogenic pulse and post-Antlerian emplacement of allochthonous rocks in northeastern NV. Ph.D. thesis, Columbia Univ.

Pack, F.J., 1906. Geology of Pioche, Nevada and vicinity. Ph.D. thesis, Columbia Univ.

Palmer, A. R., 1960. Some aspects of the early upper Cambrian stratigraphy of White Pine County, NV and vicinity. Intermountain Assoc. Pet. Geol., p. 53-58.

Palmer, A.R., and J.C. Hazzard, 1956. Age and correlation of Cornfield Springs and Bonanza King Formations in southeastern California and southern NV. AAPG Bull., v. 40, p. 2492-2499.

Parizek, R.R., W.B. White and D. Langmuir, 1971. Hydrogeology and geochemistry of folded and faulted carbonate rocks of the central Appalachian type and related land use problems. GSA; 184 p.

Park, C.F., Jr., P. Gemmill and C.M. Tschanz, 1958. Geologic map and sections of the Pioche Hills, Lincoln County, NV. USGS Mineral Inv. Field Studies Map MF-136, scale 1:12,000.

Pelton, P.J., 1966. Mississippian rocks of the southwestern Great Basin, NV and CA. Ph.D. thesis, Rice Univ.

Perkins, T.W., 1972. Paleontology and stratigraphic subdivision of the Devonian Sevy, Simonson, and lower Guilmette Formations from the West Range and vicinity, Lincoln County, NV. B.S., Univ. of Illinois.

Peterson, B.L., 1968. Stratigraphy and structure of the Antelope Peak area, Snake Mountains, Elko County, northeastern NV. M.S. thesis, Univ. of Oregon.

Phoenix, D.A., 1948. Geology and ground water in the Meadow Valley Wash drainage area, above the vicinity of Caliente, NV. USGS Water Reso. Bull. 7.

Pierce, R.W., 1967. Stratigraphy and paleontology of a portion of the Pogonip Group (lower and middle Ordovician), Arrow Canyon Range, NV. M.S. thesis, Univ. of Illinois.

Pilger, R.H., Jr., 1972. Structural geology of part of the northern Toano Range, Elko County, NV. M.S. thesis, Univ. of Neb.

Pipkin, B.W., 1956. Geology of the south third of the Green Springs quadrangle, NV. M.A. thesis, Univ. of Southern Calif.

Playford, P.E., 1961. Geology of the Egan Range, near Lund, NV. Ph.D. thesis, Stanford Univ.

Poole, F.G., 1965. Geologic map of the Frenchman Flat quadrangle, Nye, Lincoln, and Clark Counties, NV. USGS Quad. Map GQ-456, scale 1:24,000.

Poole, F.G., D.P. Elston and W.J. Carr, 1956. Geologic map of the Cane Spring quadrangle, Nye County, NV. USGS Quad. Map GQ-455, scale 1:24,000.

Poole, F.G., and F.A. McKeown, 1962. Oak Springs Group of the Nevada Test Site and vicinity, NV. in Geological Survey Research, 1962: USGS Prof. Paper 450-C, p. C60-C62.

Ptacek, A.D., 1962. Structure and stratigraphy of the Horse Range, NV. M.S. thesis, Washington Univ.

Ravenscroft, A.W., 1974. The geology of Big Bald Mountain, White Pine County, NV. M.S. thesis, San Diego State Univ.

Reade, H.L., Jr., 1962. Stratigraphy and paleontology of the Monte Cristo Limestone, Goodsprings quadrangle, NV. M.S. thesis, Univ. of Southern Calif.

Reed, W.E., 1962. The geology of the southern Cherry Creek Mountains, NV. M.S. thesis, Univ. of Calif.

Regnier, J., 1960. Cenozoic geology in the vicinity of Carlin, NV. Geol. Soc. Am. Bull., v. 71, no. 7, p. 1189-1210.

Reso, A., 1960. The geology of the Pahranagat Range, Lincoln County, NV. Ph.D. thesis, Rice Institute.

______, 1963. Composite columnar section of exposed Paleozoic and Cenozoic rocks in the Pahranagat Range, Lincoln County, NV. Geol. Soc. Am. Bull., v. 74, no. 7, p. 901-918.

Reso, A., and C. Croneis, 1959. Devonian system in the Pahranagat Range, southeastern NV. GSA Bull., v. 70, p. 1249-1252.

Rich, M., 1956. Geology of the southern portion of the Pancake Summit quadrangle, NV. Master's thesis, Univ. Southern Calif.

______, 1959. Stratigraphic section and fusilinids of the Bird Spring Formation near Lee Canyon, Clark County, NV. Ph.D. thesis, Univ. of Illinois.

______, 1960. Stratigraphic section and fusilinids of the Bird Spring Formation near Lee Canyon, Clark County, NV (abs.). GSA Bull., v. 71, p. 2039.

______, 1963. Petrographic analysis of Bird Spring Group (Carboniferous-Permian) near Lee Canyon, Clark County, NV. AAPG Bull. v. 47, p. 1657-1681.

Rigby, J.K., 1960. Geology of the Buck Mountain-Bald Mountain area, southern Ruby Mountains, White Pine County, NV. in Geology of East-central NV: Intermountain Assoc. Pet. Geol. 11th Ann. Field Conf., 1960, Guidebook, p. 173-180.

Riva, J.F., 1957. Geology of a portion of the Diamond Range, White Pine County, NV. M.S. thesis, Univ. of NV.

______, 1970. Thrusted Paleozoic rocks in northern and central HD Range, northeastern NV. Geol. Soc. Am. Bull., v. 81, p. 2689-2716.

Roberts, R.J., 1960. Alinement of mining districts of north-central NV. Geol. Survey Research 1960, PP 400B, p. B17.

______, 1964. Paleozoic rocks. in Mineral and Water Resources of NV. NV Bur. Mines Bull. 65, p. 22-25.

Roberts, R.J., P.E. Hotz, J. Gilluly, and H.G. Ferguson, 1958. Paleozoic rocks of north-central NV. Am. Assoc. Pet. Geol. Bull., v. 42, no. 12, p. 2813-2857.

Roberts, R.J., K.M. Montgomery, and R.E. Lehner, 1967. Geology and mineral resources of Eureka County, NV. NV Bur. of Mines Bull. 64, 152 p.

Roberts, W.B., 1965. Stratigraphy of the lower to middle Paleozoic carbonate sequence in the eastern Great Basin (abs.). GSA Bull., v. 67, no. 12, pt. 2, p. 1781.

Robinson, G.B., Jr., 1961. Stratigraphy and Leonardian fusilinid palenotology in central Pequop Mountains, Elko County, NV. Brigham Young Univ. Geol. Studies, V. 8, p. 93-146.

Robinson, T.W., G.B. Maxey, J.C. Federicks and C.H. Jameson, 1947. Water levels and artesian pressure in wells in Las Vegas Valley and in other valleys, NV 1913-1945. USGS Water Reso. Bull. 3.

Robison, R.A., 1960. Lower and middle Cambrian stratigraphy of the eastern Great Basin. in Intermountain Assoc. of Pet. Geol. Guidebook to Geol. of East Central NV, p. 43-52.

Ross, R.J., Jr., 1964a. Middle and lower Ordovician formations in southernmost Nevada and adjacent California. USGS Bull. 1180-C.

_______, 1964b. Relations of middle Ordovician time and rock units in Basin Ranges, western United States. Am. Assoc. Pet. Geol. Bull., v. 48, no. 9, p. 1526-1554.

Ross, R.J., Jr., and W.B.N. Berry, 1963. Ordovician graptolites of the Basin Ranges in California, Nevada, Utah, and Idaho. USGS Bull. 1134.

Rubner, D., 1969. The petrology, stratigraphy, and paleoecology of the Laketown Dolomite in east-central Nevada. M.S. thesis, Northern Illinois Univ.

Rush, F.E., 1964. Ground-water appraisal of the Meadow Valley area, Lincoln and Clark Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. -Recon. Ser. Rept. 27.

_______, 1968. Water resources appraisal of Thousand Springs Valley, Elko County, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. - Recon. Ser. Rept. 47.

_______, 1968a. Water-resources appraisal of Clayton Valley-Stonewall Flat area, NV and Calif. NV Dept. of Cons. and Nat. Reso., Water Reso. -Recon. Ser. Rept. 45.

_______, 1968c. Water-resources appraisal of the lower Moapa-Lake Mead area, Clark County, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. - Recon. Ser. Rept. 50.

_______, 1970. Regional ground-water systems in the Nevada Test Site area, Nye, Lincoln and Clark Counties, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser. Rept. 54, 25 p.

Rush, F.E. and T.E. Eakin, 1963. Ground-water appraisal of Lake Valley in Lincoln and White Pine Counties, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. - Recon. Ser. Rept. 24.

Rush, F.E. and D.E. Everett, 1964. Ground-water appraisal of Monitor, Antelope and Kobeh Valleys, NV. NV Dept. of Cons. and Nat. Reso., Ground-water Reso. -Recon. Ser. Rept. 30.

______, 1966a. Water-resources appraisal of Huntington Valley area, Elko and White Pine Counties, NV. NV Dept. of Cons. and Nat. Reso., Water-Reso. - Recon. Ser. Rept. 35, 37 p.

______, 1966b. Water resources appraisal of Little Fish Lake, Hot Creek and Little Smoky Valleys, NV. NV Dept. of Cons. and Nat. Reso., Water Reso. - Recon. Ser. Rept. 38.

Rush, F.E. and C.J. Huxel, Jr., 1966. Ground-water appraisal of the Eldorado-Piute Valley area, Nevada and California. NV Dept. of Cons. and Nat. Reso., Water Reso. - Recon. Ser. Rept. 36.

Rush, F.E. and S.A.T. Kazmi, 1965. Water-resources appraisal of Spring Valley, White Pine and Lincoln Counties, NV. NV Dept. of Cons. and Nat. Reso., Water-Reso. - Recon. Ser. Rept. 33.

Sadlick, W., 1960. Some preliminary aspects of Chainman stratigraphy. Intermountain Asso. of Pet. Geol., p. 81-90.

Sales, J.K., 1966. Structural analysis of the Basin and Range Province in terms of wrench faulting. Ph.D. thesis, Univ. of NV.

Sargent, K.A., E.J. McKay, and B.C. Burchfiel, 1970. Geologic map of the Striped Hills quadrangle, Nye County, NV. USGS Quad. Map GQ-882, scale 1:24,000.

Sargent, K.A. and J.H. Stewart, 1971. Geologic map of the Specter Range NW quadrangle, Nye County, NV. USGS Quad Map GQ-884, scale 1:24,000.

Scales, B., 1961. Geology of the Applebush Hill area, southern Antelope Valley, Nye County, NV. M.S. thesis, Univ. NV.

Schaeffer, F.E., Jr., 1961. Geology of the central and southern Silver Island Mountains, Tooek County, Utah, and Elko County, NV. Ph.D. thesis, Univ. of Utah.

Schilling, J.H., 1965. Isotopic age determinations of Nevada rocks. NV Bur. Mines Rept. 10, 79 p.

Schleh, E.E., 1963. Upper Devonian to Middle Pennsylvania discontinunity-bounded sequences in a part of the Cordilleran region. Ph.D. thesis, Univ. of Washington.

Schoff, S.L. and J.E. Moore, 1964. Chemistry and movement of water, Nevada Test Site. USGS Rept. No. TEI-838, 75 p.

______, 1968. Sodium as a clue to ground-water movement, Nevada Test Site. USGS Prof. Paper 600D, p. D30-D33.

Schrader, F.C., 1931. Notes on ore deposits at Cave Valley, Patterson District, Lincoln County, NV. Univ. of NV Bull. v. XXV, no. 3.

Schwartz, F.W. and P.A. Domenico, 1973. Simulation of hydrochemical patterns in regional groundwater flow. Water Reso. Res. 9:3, p. 707-720.

Scott, R.B., 1965. The Tertiary geology and ignimbrite petrology of the Grant Range, east-central NV. Ph.D. thesis, Rice Univ.

Seager, W.L., 1966. Geology of the Bunkerville section of the Virgin Mountains, Nevada and Arizona. Ph.D. thesis, AZ Univ.

Seager, W.R., 1970. Low angle gravity glide structures in the northern Virgin Mountains, Nevada and Arizona. GSA Bull. 81:5, p. 1517-1538.

Secor, D.T., Jr., 1963. Geology of the central Spring Mountains Nevada. Ph.D thesis, Stanford Univ.

Shank, S.E., 1957. The Devonian stratigraphy of Ward Mountain, NV. M.A. thesis, Univ. of Calif.

Sharp. J.V.A., 1969. Time-dependent behavior of water chemistry in hydrologic systems (abst.). EOA, Trans. Am. Geophys. Union 50:4, p. 141.

_______, 1970. Analysis of time-variant behavior of water chemistry (abst.). EOA, Trans. Am. Geophys. Union, 51:4, p. 282.

Sharp, R.P., 1938. Boundary structure of the Ruby-East Humboldt Range, NV. Ph.D. thesis, Harvard Univ.

_______, 1939. Basin-range structure of Ruby-East Humboldt Range, northeastern NV. GSA Bull. 50, p. 881-920.

_______, 1942. Stratigraphy and structure of the southern Ruby Mountains, NV. Geol. Soc. Am. Bull., v. 53, p. 647-690.

Shuster, E.T., W.B. White, 1971. Seasonal fluctuations in the chemistry of limestone springs: A possible means for characterizing carbonate aquifers. Jour. Hydrol. 14:93-128.

_______, 1972. Source areas and climatic effects in carbonate ground waters determined by saturation indices and carbon dioxide pressures. Water Reso. Res. 8:1067-1073.

Siddiqui, S.H., and R. R. Parizek, 1971. Hydrogeologic factors influencing well yeilds in folded and faulted carbonate rocks in central Pennsylvania, WRR 7:5.

Sides, J.W., 1966. The geology of the central Butte Mountains, White Pine County, NV. Ph.D. thesis, Stanford Univ.

Silberling, N.J. and R.E. Wallace, 1969. Stratigraphy of the Star Peak Group (Triassic) and overlying lower Mesozoic rocks, Humboldt Range, NV. USGS Prof. Paper 592, 50 p.

Silitonga, P.H., 1975. Geology of part of the Kittridge Springs quadrangle, Elko County, NV. M.S. thesis, Colorado School of Mines.

Silk, E.W., 1931. The geology and ore deposits of Hamilton, NV. M.S. thesis, Yale Univ.

Slack, J.F., 1972. Structure, petrology and ore deposits of the Indian Springs (Delano Mountains) region, Elko County, NV. M.S. thesis, Miami (Ohio) Univ.

Smith, J.F., Jr., and K.A. Howard, 1977. Geologic map of the Lee 15-minute quadrangle, Elko County, NV. USGS Map GQ-1393.

Smith, J.F., Jr., and K.B. Ketner, 1972. Geologic maps of the Dixie Flats, Robinson Mountain, Carlin and Pine Valley quadrangles, Eureka and Elko Counties, NV. USGS Misc. Field Studies Map MF-481, scale 1:125,000.

Smosna, R.A., 1973. Upper Pennsylvanian-Lower Permian stratigraphy of southern and eastern Nevada. Ph.D. thesis, Univ. of Illinois.

Snelson, S., 1955. The geology of the southern Pequop Mountains, Elko County, northeastern NV. Master's thesis, Washington Univ.

_______, 1957. The geology of the northern Ruby Mountains and the East Humboldt Range, Elko County, NV. Ph.D. thesis, Washington, Univ.

Snow, G.G., 1963. Mineralogy and geology of the Dolly Varden Mountains, Elko County, NV. Ph.D. thesis, Utah Univ.

Southwick, R., 1962. Geology of the south-central part of the Schell Peaks quadrangle, NV. M.A. thesis, Univ. of Southern Calif.

Spencer, A.C., 1917. The geology and ore deposits of Ely, NV. USGS Prof. Paper 96.

Stearns, N.D., H.T. Stearns, and G.A Waring, 1937. Thermal springs in the United States. USGS Water-supply paper 679-B, 206 p.

Steele, G., 1959. Stratigraphic interpretation of Pennsylvanian-Permian systems of the eastern Great Basin. Ph.D. thesis, Washington Univ.

_______, 1960. Pennsylvanian-Permian stratigraphy of east-central Nevada and adjacent Utah, in Intermountain Assoc. Pet. Geol. Guidebook, 11th Ann. Field Conf., east-central NV. 1960; p. 91-113.

Steininger, R., 1966. Geology of the Kingsley Mining District, Elko County, NV. M.S. thesis, Brigham Young Univ.

Stensaas, L.J., 1957. Paleontology and stratigraphy of the Joana Limestone at Ward Mountain, NV. M.A. thesis, Univ. of Calif.

Stevens, C.H., 1963. Paleoecology and stratigraphy of pre-Kaibab Permian rocks in the Ely basin, NV and UT. Ph.D. thesis, Univ. of Southern Calif.

Stevens, C.H., 1965, Pre-Kaibab Permian stratigraphy and history of Butte Basin, NV and UT. Am. Assoc. Pet. Geol. Bull., v. 49, no. 2, p. 139-156.

Stewart, J.H., 1962. Variable facies of the Chainman and Diamond Peak Formations in western White Pine County, NV. in Geol. Survey Research 1962: USGS Prof. Paper 450-C, p. C57-C60.

______, 1964. Precambrian and lower Cambrian rocks. In Mineral and Water Resources of Nevada. NV Bur. Mines Bull. 65, p. 21.

______, 1970. Upper Precambrian and lower Cambrian strata in the southern Great Basin, Calif, and NV. USGS Prof. Paper 620, 206 p.

______, 1971. Basin and Range structure: a system of horsts and grabens produced by deep-seated extension. GSA Bull., v. 82, p. 1019-1044.

Stewart, J.H., and J.E. Carlson, 1977. Million-scale geologic map of Nevada. NV Bur. of Mines & Geol. Map 57.

Stieglitz, R.D., 1967. Sedimentary structures in Canadian through Giventian rocks, Arrow Canyon Range, Clark County, NV. M.S. thesis, Univ. of Illinois.

Stock, C., 1921a. Later Cenozoic mammalian remains from the Meadow Valley region, southeastern NV (abs.). GSA Bull., v. 32, p. 146-147.

______, 1921b. Later Cenozoic mammalian remains from the Meadow Valley region, southeastern Nevada. Am. Jour. Sci., 5th ser., v. 2, p. 250-264.

Stone, R.W., et al., 1920. Gypsum deposits of the U.S. USGS Bull. 697.

Stricker, G.D., 1973. Carbonate microfacies of the Pogonip Group (lower Ordovician) Arrow Canyon Range, Clark County, NV. Ph.D. thesis, Univ. of Illinois.

Stringfield, V.T. and H.E. LeGrand, 1969. Hydrology of carbonate rock terranes. Am. Review. Jour. of Hydro. 9:349-417.

Tabor, L.L., 1970. Geology of the Las Vegas Area. John A. Blume and Assoc., Res. Div., San Francisco, Calif., 32 p.

Taylor, J.B., 1963. The geology of the Indian Springs region, Clark County, NV. M.S. thesis, Univ. of Calif.

Thorman, C.H., 1960. Geology of the Wood Hills, Elko County, NV. M.S., Univ. of Washington.

______, 1970. Metamorphosed and nonmetamorphosed Paleozoic rocks in the Wood Hills and Pequop Mountains, northeast NV. Geol. Soc. Am. Bull., v. 81, p. 2417-2448.

Thrailkill, J.V., 1972. Carbonate chemistry of aquifer and stream water in Kentucky. Jour. of Hydro. 16:93-104.

Toth, J., 1962. A theory of groundwater motion in small drainage basins in central Alberta, Canada. Jour. Geophy. Res. 67:11, p. 4375-4387.

Toth, J., 1963. A theoretical analysis of groundwater flow in small drainage basins. Jour. Geophy. Res. 68:16, p. 4795-4812.

Tripp, E.C., 1957. The geology of the north half of the Pancake Summit quadrangle, NV. M.S. thesis, Univ. Southern Calif.

Trummel, J.E., 1972. Stratigraphy of the Guilmette Formation, West Range, Lincoln County, NV. B.S., Univ. of Illinois.

Turner, N.L., 1963. Geology of the Ruth quadrangle, White Pine County, NV. M.S. thesis, Univ. of Southern Calif.

Tschanz, C.M., 1960. Geology of northern Lincoln County, NV. in Guidebook to the geology of east-central NV. Intermountain Assoc. Pet. Geol. and Eastern NV Geol. Soc., 11th Ann. Field Conf., Salt Lake City, Utah, p. 198-208.

Tschanz, C.M. and E.H. Pampeyan, 1961. Preliminary geologic map of Lincoln County, NV. USGS Mineral Inv. Field Studies Map MF-206.

_______, 1970. Geology of Lincoln County, NV. NV. Bur. Mines and Geol. Bull. 73, 187 p.

U.S. Bureau of Reclamation, 1950. Geological investigations. U.S. Bur. of Reclam., Boulder Dam Proj., Final Rept., pt. 3, Bull. 1.

VanDenburgh, A.S. and F.E. Rush, 1974. Water resources appraisal of Railroad and Penoyer valleys, east-central NV. NV Dept. of Cons. and Nat. Reso., Water Reso. Recon. Ser. Rept. 60.

Vanderburg, W.O., 1937. Reconnaissance of mining districts in Clark County, NV. U.S. Bur. Mines Inf. Circ. 6964.

Van Houten, F.B., 1956. Reconnaissance of Cenozoic sedimentary rocks of Nevada. Am. Assoc. Pet. Geo. Bull., v. 40, no. 12, p. 2801-2825.

Vincelette, R.R., 1964. Structural geology of the Mt. Stirling Quad, Nevada, and related scale-model experiments. Ph.D. thesis, Stanford Univ., 141 p.

Volborth, A., 1962. Rapakivi-type granite in the Precambrian complex of Gold Butte, Clark County, NV. GSA Bull. v. 73, p. 813-832.

Waite, R.H., 1956. Upper Silurian brachiopoda from the Great Basin. Jour. Paleontology, v. 30, no. 1, p. 15-18.

Waldbaum, R., 1970. Geology of the Portuguese Mountain area, Nye County, NV. M.S. thesis, San Diego State.

Walker, G.E. and T.E. Eakin, 1963. Geology and ground water of Amargosa Desert, Nevada-California. NV Dept. of Cons. and Nat. Res., Water Reso. Recon. Ser. Rept. 14.

Walker, L.G., 1962. Geology of the Mt. Hope area, Garden Valley quadrangle, NV. M.S. thesis, Univ. Calif. Los Angeles.

Wallace, R.E., 1964. Topography. in Mineral and water reso. of NV. NV Bur. of Mines Bull. 65, p. 11-12.

______, 1964. Structural evolution, in Mineral and water reso. of NV. NV Bur. Mines Bull. 65, 32-39.

Ward, R., 1962. Geology of the northern half of the Reipetown quadrangle, NV. M.A. thesis, Univ. of Southern Calif.

Waring, G.A., 1965. Thermal springs of the United States and other countries of the world, a summary, USGS Prof. Paper 492.

Watson, J.G., 1939. The lower Carboniferous of the Diamond Peak area, NV. M.S. thesis, Cornell Univ.

Webb, G.W., 1956. Middle Ordovician detailed stratigraphic sections for western Utah and eastern Nevada. Utah Geol. and Mineralog. Sur. Bull. 57.

______, 1958. Middle Ordovician stratigraphy in eastern Nevada and western Utah. Am. Assoc. Pet. Geol. Bull., v. 42, p. 2335-2377.

Welsh, J.E., 1959. Biostratigraphy of the Pennsylvanian and Permian systems in southern Nevada. Ph.D. thesis, Univ. of Utah.

Westgate, L.G. and A. Knopf. 1927. General geology, pt. 1 of Geology of Pioche, NV. and vicinity. Am. Inst. Mining Metall. Eng. Trans., v. 75, p. 816-828.

______, 1932. Geology and ore deposits of the Pioche district, NV. USGS Prof. Paper 171.

Wheeler, H.E., 1943. Lower and middle Cambrian stratigraphy in the Great Basin area. GSA Bull., v. 54, p. 1781-1822: 1944, reprinted as NV Univ. Bull., v. 38, no. 3, Geol. and Min. Ser., no. 39.

White, W.B., 1969. Conceptual models for limestone aquifers. Ground Water 7, p. 15-21.

______, 1977. Conceptual models for carbonate aquifers: revisited. in Hydrologic problems in Karst Regions, Ed. by R.R. Dilamarter and S.C. Csallany, Western Kentucky Univ., p. 176-187.

Whitebread, D.H., 1970. Geologic map of the Wheeler Peak and Garrison quadrangles, Nevada and Utah. USGS Misc. Geol. Inv. Map I-578, scale 1:48,000.

Whitebread, D.H., A.B. Griggs, W.B. Rogers and J.W. Mytton, 1962. Preliminary geologic map and sections of the Wheeler Peak quadrangle, White Pine County, NV. USGS Mineral Inv. Field Studies Map MF-244.

Whitney, J.W., 1971. Geology of the Heusse Mountain Pluton, White Pine County, NV. M.S. thesis, Univ. of Neb.

Whitten, C.A., 1956. Crustal movement in California and Nevada. AGU, Trans, v. 37, p. 393-398.

Wilber, H.T., 1971. Geology of a portion of the Las Vegas Range, Clark County, NV. B.S., Univ. of Illinois.

Wiese, J.H., 1960. The penetration chart of significant Nevada wildcats. in IAPG Guidebook, p. 232.

Willden, C.R., and R.W. Kistler, 1969. Geologic map of the Jiggs quadrangle, Elko County, NV. USGS Quad. Map GQ-859, scale 1:62,500.

______, 1967. Isoclinally folded eastern Facies rocks of Antler orogenic belt in central Ruby Mountains, NV. GSA Spec. Paper 101, p. 346-347.

______, 1967. Ordovician tectonism in the Ruby Mountains, Elko County, NV. USGS Prof. Paper 575D, p. 64-75.

Willden, R., H.H. Thomas, and T.W. Stern, 1967. Oligocene or younger thrust faulting in Ruby Mountains, northeastern NV. GSA Bull. v. 78, p. 1345-1358.

Williams, P.L., 1967. Stratigraphy and petrology of the Quichapa Group, southwestern Utah and southeastern NV. Ph.D. thesis, Univ. of Washington.

Wilson, C.L., 1938. The geology of the Black Forest mine area, Spruce Mt., NV. M.S. thesis, Univ. of Arizona.

Wilson, E.C., 1960. Pennsylvanian and Permian paleontology and stratigraphy of Ward Mt., White Pine County, NV. M.A., Univ. of Calif.

Winfrey, W.M., 1958. Stratigraphy, correlation, and oil potential of the Sheep Pass Formation, east-central NV. 1958 Geol. Rec., Rocky Mtn. Sec., AAPG, p. 77-82.

______, 1960. Stratigraphy, correlation, and oil potential of the Sheep Pass Formation, east-central NV. Intermountain Assoc. Pet. Geol. and Eastern NV Geol. Soc. 11th Ann. Field Conf., p. 126-133.

Winograd, I.J., 1962. Interbasin movement of ground water at the Nevada Test Site, NV. USGS Prof. Paper 450C, p. C108-C111.

______, 1963. A summary of the ground water hydrology of the area between the Las Vegas Valley and the Armagosa Desert, NV with special reference to the effects of possible new withdrawals of ground water. USGS Open-FILE Rept. TEI-840, 79 p.

______, 1971. Origin of major springs in the Armagosa Desert of Nevada and Death Valley, California. Ph.D. thesis, Univ. of Arizona.

Winograd, I.J. and I.J. Friedman, 1972. Deuterium as a tracer of regional ground-water flow, southern Great Basin, Nevada and California. GSA Bull. 83:12, p. 3691-3708.

Winograd, I.J. and F.J. Pearson, 1976. Major carbon 14 anomaly in a regional carbonate aquifer: possible evidence for mega scale channeling, south central Great Basin. Water Reso. Res. 12:6, p. 1125-1143.

Winograd, I.J. and W. Thordarson, 1968. Structural control of ground-water movement in miogeosynclinal rocks of south-central Nevada. in Nevada Test Site, E.B. Eckel ed., Geol. Soc. Am. Memoir 110, p. 35-48.

______, 1975. Hydrogeologic and hydrochemical framework, south-central Great Basin, Nevada - California with special reference to the Nevada Test Site. USGS Prof. Paper 712-C, 126 p.

Winter, J.K., 1969. Geology of the northern half of the West Range, Lincoln County, NV. B.S., Univ. of Illinois.

Winterer, E.L., 1968. Tectonic erosion in the Roberts Mountains, Nevada. Jour. Geol., v. 76, no. 3, p. 347-357.

Winterer, E.L. and M.A. Murphy, 1960. Silurian reef complex and associated facies, central Nevada. Jour. Geol., v. 68, no. 2, p. 117-139.

Wire, J.C., 1961. Geology of the Currant Creek district, Nye and White Pine Counties, NV. M.A. thesis, Calif. Univ., Los Angeles.

Woodward, L.A., 1962. Structure and stratigraphy of the central northern Egan Range, White Pine County, NV. Ph.D. thesis, Washington Univ.

Young, J.C., 1960. Structure and stratigraphy in north-central Schell Creek Range, in Geology of east-central NV. Intermountain Assoc. Pet. Geol., 11th Ann. Field Conf., 1960 Guidebook, p. 158-172.

Zabriskie, W.E., 1967. Petrology and petrography of Permian carbonate rocks, Arcturus Basin, Nevada and Utah. Ph.D. thesis, Brigham Young Univ.

APPENDIX I

Lithologic Description of Paleozoic Rocks in Eastern Nevada

Lithologic descriptions in this appendix were taken from many sources. The majority of the descriptions are from the following list of references: Bissel (1962b), Boettcher and Sloan (1960), Cornwall (1972), Decker (1962), Drewes (1967), Ebands (1965), Fleck (1967), Granger et. al. (1957), Hose and Blake (1976), Johnson and Hibbard (1957), Kay and Crawford (1964), Langenheim et. al. (1962), Langenheim and Larson (1973), Longwell et. al. (1965), Merriam (1963), Roberts et. al. (1967), and Tschanz and Pampeyan (1970).

CAMBRIAN

Prospect Mountain Quartzite (Thickness of 130 to 4500 feet): Light-gray to dark-purplish-gray, thick-bedded, cross-bedded quartzite and metaquartzite. Contains some interbedded olive-drab and brown arenaceous shale. In eastern Clark County, Nevada, consists chiefly of gray to brown, in part arkosic, locally cross-bedded sandstone, with beds a few inches to 2 or 3 feet thick.

Wood Canyon Formation (2100 to 2500 feet): Highly variable formation consisting of multicolored quartzites, sandstones, shales, siltstones and a few thin beds of impure dolomite.

Zabriskie Quartzite (20 to 200 feet): Homogenous sequence of pale-red, fine-to coarse-grained quartzite with minor interbedded purple siltstone, especially at the base.

Pioche Shale (200 to 640 feet): Olive-black to greenish-gray shale, with some brown to reddish-purple beds. Contains some interbedded sandstones, limestones and quartzites. In surface outcrops commonly forms a swale between more resistant units.

Lyndon Limestone (85 to 400 feet): Gray-brown, massive-bedded, fine-to medium-grained limestone with abundant shaly limestone mottling. Resistant unit that generally stands out as a single cliff or series of cliffy steps.

Chisholm Shale (70 to 170 feet): Predominantly green but locally brownish, finely micaceous fissile shale which contains a few thin limestone beds. In surface outcrops forms a prominent slope separating cliffs of underlying and overlying limestones.

Carrara Formation (760 to 1960 feet): Varied assemblage of shale and limestone, equivalent to the Pioche Shale, Lyndon Limestone and Chisholm Shale.

Edgemont Formation (700 ± feet): Consists of blue-gray to brown, sandy schistose quartzite in the lower part of the formation and calcareous slate in the upper part.

Bonanza King Formation (2000 to 4590 feet): Thick sequence of predominantly limestone and dolomite. Two members have been recognized; the lower member, Papoose Lake, is a sequence of limestone which grades upward into dolomite; and the upper member, Banded Mountain, is a sequence of dolomitic rocks which grades upward into more calcareous rocks.

Peasley Limestone (750 ± feet): This is a unit recognized in the Virgin Mountains, Clark County, Nevada. It consists largely of gray limestone with yellowish mottling.

Undifferentiated Dolomite and Limestone (900 to 6000 feet): Thick sections of carbonate rocks of Middle and Late Cambrian Age found in Clark County, Nevada. There is no consistent nomenclature for the division of this section. The total section thickens greatly from east to west. This section of carbonate rocks, in southern Nevada, is sometimes referred to as the Bonanza King Formation.

Pole Canyon Limestone (1585 to 2000 feet): Medium-gray and light-gray, fine-to medium-coarse-grained limestone. Contains some local lenses of dolomite and a few local quartzite beds near the base.

Eldorado Dolomite (2000 to 2500 feet): Consists of thick-bedded to massive pale-gray beds that range from nearly pure limestone to nearly pure dolomite. Most common lithologic type is a light-gray, rather coarsely-crystalline dolomite.

Geddes Limestone (330 ± feet): Dark-bluish-gray to black, well-bedded, moderately fine-grained limestone. It is carbonaceous and has very thin shaly partings. Small amounts of nodular black chert occur at the top of the formation.

Patterson Pass Shale (2000 ± feet): Yellowish or gray shale and calcareous mudstone with interbedded limestone (the limestone is more abundant near the top).

Lincoln Peak Formation (1600 to 4500 feet): Predominantly very thin-bedded, medium-dark-gray limestone and shaly limestone, interbedded with clay shale and calcareous shale.

Secret Canyon Shale (110 to 650 feet): Consists of a lower shale member which is a fairly uniform, black argillaceous shale with little or no interbedded limestone, and an upper unit of dominantly thin-bedded, platy limestone with yellow or red shale partings.

Porter Peak Limestone (3200 ± feet): The upper two-thirds of the formation consists of massive blue-gray limestone. The lithology of the lower third of the formation is more complex. It consists of tan dolomitic limestone, gray siltstone, black shaly limestone and limestone conglomerate.

Highland Park Formation (2000 ± feet): Predominantly dolomite.

Emigrant Springs Limestone (1950 to 2232 feet): Consists of thin-bedded, silty or oolitic limestone and massive limestone. Contains some mudstone.

Johns Wash Limestone (250 ± feet): Consists mainly of coarse-textured, organic-detrital limestone and ooidal to pisolitic limestone, partly cross-bedded. Both are light olive gray to dark gray in color.

Swarbrick Limestone (2700 ± feet): Structurally disturbed limestone.

Hamburg Dolomite (1000 to 3000 feet): Predominantly gray, thick-bedded, coarsely crystalline limestone and dolomitic limestone. Locally contains intraformational conglomerates. Basal unit of dark-blue limestone beds, which alternate with thinner beds of platy limestone. Above the limestone is well-banded saccharoidal dark dolomite.

Goodsprings Dolomite (2500 ± feet): Predominantly thin-bedded, light- and dark-gray mottle dolomite. A 50 to 75 foot layer of dolomitic limestone and sandy shale is found locally near the top of the formation. This formation ranges in age from Cambrian to Devonian.

Dunderberg Shale (200 to 320 feet): Consists of approximately equal thicknesses of olive-drab or tan fissile shale and zones of interbedded shale, with thin, nodular limestone. The limestones are dense to medium grained and are blue-gray on fresh surfaces. Weathered surfaces are browner and commonly show a fine banding or lamination.

Corset Springs Shale (65 to 320 feet): Lithologically similar to the Dunderberg Shale. Consists chiefly of light-olive-gray silty shale, with thin interbeds of limestone.

ORDOVICIAN

Pogonip Group (610 to 3390 feet): Predominantly limestone, dolomite and a relatively small amount of shale. The most common rock types are thin- to medium-bedded limestone; orange-brown silty limestone and light-gray dolomite.

Eureka Quartzite (100 to 550 feet): Vitreous, white quartzite with some interbedded gray dolomite at the upper and lower contacts. The quartzite is medium to coarse grained and contains few impurities. Forms massive cliffs.

Vinini Formation (500 to 1000 feet): Highly variable formation ranging from coarse sandstone and siltstone to black shale, bedded chert, and limestone. Chloritized lava flows and tuffs are found locally.

Ely Springs Dolomite (130 to 850 feet): Known locally as the Fish Haven Dolomite and the Hanson Creek Formation. It is predominantly dolomite which is medium dark gray on fresh fractures; on weathered surfaces it is mostly dark olive gray. The texture is finely crystalline to crypto-crystalline. Locally contains some small chert nodules. The formation is made up of beds that are a few inches to 15 feet in thickness; usually forms slopes interrupted by a series of ledges.

Aura formation (3800 ± feet): Contains a basal member of brown to black phyllite and chert alternating with blue-gray limestone. Limestone beds in this unit are up to 300 feet thick. The middle member is buff colored, medium-grained, vitreous quartzite, which is lenticular. The upper member is brown to black laminated phyllites inter-bedded with calcareous layers.

SILURIAN

Laketown Dolomite (265 to 1000 feet): Medium-dark-gray, weathers olive-gray, fine-grained dolomite. In most places this formation contains from one to three thick and prominent layers of light-olive-gray dolomite that weathers yellowish gray. Near the middle of the formation, there is commonly a layer of quartzitic chert 3 to 10 feet thick.

Roberts Mountain Formation (500 to 1900 feet): Predominantly platy, silty limestone and minor amounts of dolomite in the upper portion of the formation. The lower part of the formation consists of silicious, dark-slate-gray, fine- to medium-grained limestone with interbeds of bluish-black chert.

Lone Mountain Dolomite (1000 to 2200 feet): Light- to medium-gray, fine- to medium-grained, massive, homogenous dolomite.

Chellis Limestone (1900 ± feet): Blue-gray, finely-crystalline, laminated to massive limestone with numerous calcite seams. Contains some argillaceous and dolomitic beds.

Storff Formation (3900 ± feet): Consists of black to brown, thin-bedded phyllites and slates with interbedded argillaceous limestone. Pyrite cubes are locally common in the metamorphosed shale.

DEVONIAN

Sevy Dolomite (250 to 1580 feet): Medium-gray, very fine-grained dolomite that weathers light gray to yellowish gray, locally includes layer of darker dolomite. The beds range in thickness from 6 inches to 6 feet and average about 1-1/2 to 2 feet. Thin beds of medium- to coarse-grained quartz sandstone occur locally in the upper 100 feet.

Piute Formation (300 to 320 feet): Consists mostly of gray, medium- to fine-grained, buff-weathering dolomite which crops out in beds 1 to 5 feet thick. Commonly contains a basal sandstone unit.

Moapa Formation (300 ± feet): The lower part of this formation is predominatly thin- to medium-bedded dolomite which weathers light gray to buff. The upper part of the formation is gray to light-gray, buff to yellow-weathering, thin- to medium-bedded dolomite and limestone.

Nevada Formation (1070 to 3825 feet): Predominantly a light- to dark-gray, medium-to fine-grained dolomite. Locally contains beds of limestone, sandstone and quartzite.

Simonson Dolomite (1000 to 1500 feet): Light-brown to dark-brown, laminated, coarse-grained dolomite that weathers to an olive gray color. Can be divided into five members of which the "brown cliff" member is the most distinctive.

Sultan Limestone and **Muddy Peak Limestone** (600 ± feet): The name Sultan Limestone is used generally in the western and northwestern parts of Clark County, Nevada and the name Muddy Peak Limestone in the Muddy and Virgin Mountains, Nevada. Generally, these formations are mainly dolomite in the lower parts and limestone in the upper parts. The northern sections contain gray sandstone layers 5 to 10 feet thick and up to 60 feet thick in the upper parts of the formation.

Arrow Canyon Formation (1100 ± feet): Predominantly medium- to dark-gray, thin- to medium-bedded limestone. Contains minor interbeds of quartzite, dolomite and sandstone.

Devil's Gate Limestone (1000 to 1670 feet): Light- to dark-gray and blue-gray limestone, with minor dolomite. Sandstone or quartzite and calcareous beds up to 100 feet thick occur in the upper part of the formation.

Guilmette Formation (1600 to 2700): Predominatly even-bedded, dark-gray to grayish-black limestone that weathers olive gray to medium light gray. Most of the beds are 1 to 5 feet thick, but some are thin bedded and some form thick, massive beds. In many sections as much as 30 percent of this formation is dolomite.

Crystal Pass Limestone (160 to 280 feet): Homogeneous formation composed of light-gray, very fine-grained limestone. Weathers white and forms prominent, white cliffy slopes.

Narrow Canyon Limestone (175 to 214 feet): Consists of dark-gray, silty limestone in beds less than an inch thick. It weathers into thin buff-colored plates and forms talus covered slopes.

West Range Limestone (140 to 390 feet): Predominantly medium-gray or olive-gray, very clayey limestone. Contains some interbeds of shale and mudstone.

Van Duzer Limestone (5000 to 7200) feet: Blue-gray to nearly white, well-bedded limestone, ranging from massive, nearly pure calcareous beds to paper-thin laminations of shaly limestone.

Pilot Shale (70 to 950 feet): Olive-gray dolomitic silt-stone interbedded with silty shale that weathers dusky yellow gray. Contains some thin beds of quartzite, argillite, and limestone.

MISSISSIPPIAN

Monte Cristo Group (750 to 1300 feet): Five units are recognizable in this group. All are medium- to dark-gray, medium- to coarse-grained, highly fossiliferous limestones with only minor amounts of dolomites. Contains some chert and gray shale.

Mercury Limestone (115 ± feet): Consists of dark-gray, poorly-bedded and cherty, crinoidal limestone. Forms resistant ledges.

Eleana Formation (7700 ± feet): Consists of yellowish-brown to pale-red laminated argillite; brown silicious siltstone; quartzite; conglomerate; and minor amounts of gray and brown crystalline limestone.

Joana Limestone (90 to 1100 feet): Predominantly massive, medium-gray to medium-light-gray, organic-detrital imestone. Generally forms resistant somewhat rounded ledges or cliffs, but it includes some zones in which the beds are no more than a foot thick, and these zones form ragged ledgy slopes. Some of the limestone contains nodules of chert.

White Pine Group (800 to 4000 feet): Predominantly very dark-gray to black shale and olive-gray platy siltstone or silty shale. The lower unit is mainly a calcareous siltstone. Contains some minor beds of organic-detrital limestone, quartzite and quartzitic siltstone.

Scotty Wash Formation or Quartzite (150 to 800 feet): Consists largely of varicolored, fine- to medium-grained quartz sandstone and quartzite. Usually poorly exposed due to the presence of olive-gray shale and limestone interbeds.

Diamond Peak Formation or Quartzite (900 to 3500 feet): Consists of interbedded cobble and pebble conglomerate, sandstone, shale and limestone. Conglomerate beds containing cobbles and pebbles of quartzite and chert are most abundant in the lower and middle parts of the formation. Limestone and shale are most common in the upper parts of the formation.

PENNSYLVANIAN

Bird Springs Group (2500 to 7000 feet): Consists of a weak basal member of sandstone, shale and thin limestone. Above this basal member it is predominantly cherty limestone and dolomite; massive, cliff-forming limestone; buff-weathering, sandy, platy limestone; and ledge forming, massive limestone. Layers of shale and sandstone recur at many horizons.

Callville Limestone (700 to 1350 feet): Gray to dark-gray, medium-bedded, fine-to medium-crystalline limestone, with numerous interbeds of sandstone and dolomitic limestone in the upper part. Nodules and lenses of gray chert recur at many horizons.

Tippipah Limestone (3600 to 4000 feet): Lithologically very similar to the Bird Springs Group. Consists of limestone with interbeds of pebbly and silty limestone. Gray to light-brown beds of resistant and nonresistant limestone 5 to 50 feet thick alternate throughout most of the formation.

Ely Group (1500 to 3500 feet): Predominantly medium-gray, organic-detrital limestone and medium-gray to yellowish-gray silty limestone. The limestone contains abundant nodules, concretions, lenses and bands of chert. Locally contains beds of dolomitized limestone and chert pebble conglomerate.

Schoonover Formation (8500 ± feet): Thick sequence of diverse rock types. Dark-gray and black bedded chert; dark siliceous argillites, and certain detrital rocks are found throughout the formation. The Schoonover Formation is considered to be part of an allochthonous chert-turbidite-volcanic assemblage.

Strathearn Formation (1500 ± feet): Variable formation consisting of quartz-silty limestone; thin, commonly cross-bedded, chert granule or quartz-sandy conglomeratic limestone; calcareous conglomerate; and calcareous quartz siltstones.

PERMIAN

Pakoon Formation (700 to 1240 feet): Predominantly pale-orange to light-gray, fine- to coarsely-crystalline dolomite. Beds are 1 to 4 feet thick and contain some soft, very light-gray dolomite. Contains some minor beds of limestone, sandstone and gypsum.

Riepe Springs Limestone (125 to 230 feet): Medium-gray, organic-detrital limestone and medium-gray to yellowish-gray, silty limestone. Very similar to the Ely Limestone but contains more massive beds and dolomitization.

Riepetown Formation (150 ± feet): Siltstone and limestone.

Arcturus Group (4925 ± feet): Thick sequence of predominantly sandstones and limestones. The lower part of this group consists mainly of very fine-grained to medium-grained, yellowish-gray, calcareous sandstone with some thin beds of dolomite and silty limestone. The middle unit in this group consists mainly of massive, light-olive-gray to cream colored limestone, much of which is sandy or silty. Contains some interbeds of siltstone and sandstone. The upper part of the Arcturus Group consists mainly of very fine-grained, yellowish-gray calcareous sandstone and siltstone.

Carbon Ridge Formation (1400 to 3200 feet): Consists chiefly of silty, sandy, thin-bedded, dark-gray, carbonaceous limestone with partings of dark colored calcareous shale and silt. The formation also contains beds of sandstone; siltstone; much conglomerate with pebbles of chert and limestone; and interbeds of light-gray, coarse-grained, organic-detrital limestone.

Garden Valley Formation (5000 ± feet): The most abundant rock types in this formation are limestone; cobble conglomerate; and arenaceous limestone. This formation also contains some pebbly limestone, siltstone, sandstone and chert pebble conglomerate.

Buckskin Mountain Formation (1200 ± feet): Predominantly light-buff and tan limestone with much included quartz silt and numerous thin interbeds of gray-brown, clean limestone. Contains a few beds of brown chert.

Beacon Flat Formation (2800 ± feet): Consists of a lower member of silty limestone interbedded with clean, gray and tan limestone containing gray chert beds and nodules. The upper member is gray, massive, fine- to coarse-grained limestone, which also contains gray chert beds and nodules.

Carlin Canyon Formation (1225 ± feet): Predominantly yellow-tan, quartzose limestone. Contains massive inter-beds of brown chert and thin beds of clean, grayish-brown limestone.

Supai Formation, Queantoweap Sandstone, Hermit Slate (1100 to 1550 feet): Because of uncertainties in correlating these units with their occurence in the Colorado Plateau, they have been referred to in Clark County as the Permian red beds. In a general way these formations contain two major units: a lower member consisting chiefly of pinkish-gray sandstone, thick bedded and prominently cross-bedded, and an upper member made up chiefly of reddish sandy shale and fine-grained sandstone.

Coconino Sandstone (90 to 120 feet): Whitish to pink, cross-bedded sandstone. Forms a prominent band between the Permian red beds beneath and the Toroweap Formation above.

Toroweap Formation (425 to 450 feet): This formation consists of a basal unit of interlayered sandstone and shale with considerable gypsum; a middle unit of limestone that is in part distinctly bedded but locally appears massive except for irregular stripes of chert; a top unit of shale and sandstone, commonly with some gypsum.

Kaibab Limestone (100 to 515 feet): Consists mainly of light-gray to dark-gray, medium-coarse to very coarse-grained, massive limestone which contains abundant chert.

Harrisburg Formation (150 to 315 feet): Consists of reddish shale, gypsum, layers of light-gray limestone and dolomite rich in chert nodules. Contains quantities of nearly pure gypsum.

Park City Group (700 to 2300 feet): Consists of medium- to very coarse-grained, light-gray to light-brownish-gray, organic-detrital limestone and yellowish-gray, fine-grained dolomite which contains much chert.

APPENDIX II

Carbonate Springs in Eastern Nevada

Abbreviations:

E	-	estimated
V	-	variable
SL	-	small local
L	-	local
R	-	regional
*	-	concentration is in equivalent parts per million (epm)
DRI	-	Desert Research Institute
USGS	-	United States Geological Survey
HNSC	-	Hazelton-Nuclear Science Corp. Palo Alto, California
AES	-	Agricultural Experiment Station, University of Nevada
NSDH	-	Nevada State Department of Health and Welfare
LLL	-	Lawrence Livermore Laboratory Livermore, California
Johnson	-	Environmental Controls on Occurrence and Chemistry of Ground Water in a Carbonate Terrane of Eastern Nevada (Master's Thesis, Carl Johnson)
USBR	-	United States Bureau of Reclamation
BLM	-	Bureau of Land Management

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (µmohs/cm)	TDS (mg/ℓ)	Temp. (F°)	pH	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)	HCO_3 (mg/ℓ)	System Class	Source of Information
Crittenden Springs NW/SE/8/42N/69E	6/28/66	5280	Paleozoic Limestone	1000 E	401		61	8.01	48	15	- 22	-	18	35	205	L	USGS
Thousand Springs SW/NW/8/40N/69E	9/25/65	4950	Paleozoic Carbonate	1350			69		- 3.82*	-	- 0.48*	-	- 1.06*	-		L	HNSC
Foothill Spring SW/SE/18/36N/62E	9/26/65	5800	Limestone	200 E			60		- 3.24*	-	- 0.62*	-	- 0.43*	-		L	HNSC
Wright Ranch Spring NE/NE/30/36N/62E	9/26/65	5800	Limestone	450 E			55		- 3.19*	-	- 0.58*	-	- 0.38*	-		L	HNSC
--- 10/39N/51E	6/27/56					1160		8.1	242	43	28	16	14	635	272	R	USGS
Mountain City 46N/53E	10/4/72					178		8.37	51	2.0	- 9.0	-	5.0	6.0	146		NSHS
Jarbridge Blo Coon Cr 31/46N/58E	11/19/72					734		8.07	75	36	- 129	-	128	124	343	R	NSHS
Bill Gibbs Ranch Wells 32/43N/60E	2/8/72					354		7.43					3.0	51	303		NSHS
Ralph's Warm Spring 33/36N/64E	9/26/65	5700	Paleozoic Carbonate	1193			70		- 3.06*	-	- 0.69*	-	- 0.68*	-		L	HNSC
Johnson Ranch Spring NW/NW/33/36N/66E	9/26/65	5700	Paleozoic Carbonate	2588		191	67		48	15	- 8.3	-	11	13	160	SL-L	HNSC
Carlin Town of 27/33N/52E	1/18/72					322		7.84	50	13	- 17	-	16	50	205	R	NSHS
8 mi. SW of Shafter, NV 33N/65E	8/28/17					263			41	20	- 29	-	12	38	215		USGS
Warm Springs SW/SE/12/33N/61E	9/26/65	5700	Paleozoic Carbonate	2250		398	63		52	20	- 63	-	23	39	334	R	NSS
Crescent Valley 36/31N/48E	6/13/48					424			30	5.7	- 89	-	42	71	188	R	USGS
Crescent Valley 1/29N/48E	6/9/48					1140			53	43	- 319	-	44	117	980	R	USGS
Pine Valley 21/29N/52E	3/6/73					488		8.73	5	2	- 162	-	14	101	249	R	NSHS
Buckhorn 23/29N/52E	5/7/72					767		7.37	111	68	- 46	-	22	258	434	R	NSHS
Odger Ranch Spring SW/SE/23/29N/63E	6/15/66	6000	Paleozoic Carbonate	200 E			65		- 4.38*	-	- 0.69*	-	- 1.39*	-		L-R	DRI
Twin Springs NE/NE/35/29N/63E	6/15/66	6200	Paleozoic Carbonate	200 E	296		69	8.10	29	21	- 12	-	5	33	174	L	USGS
Hot Creek Springs SW/NW/12/28N/52E	9/27/65	5680	Limestone	5900			84		- 3.77*	-	- 0.53*	-	- 0.74*	-		L	HNSC
Brown Ranch Spring SW/NW/28/28N/56E	10/20/64	5880	Paleozoic Carbonate	90	399			7.90	50	10	22		7.5	14	232	L	USGS
Taylor Spring SE/SE/11/28N/61E	6/15/66	6100	Paleozoic Carbonate	550E	330		61	8.0	37	16	- 11	-	7.9	19	183	L	USGS
Currie Gardens 36/28N/63E	9/10/66	6000	Paleozoic Carbonate	450 E			57		- 3.46*	-	- 0.28*	-	- 0.39*	-		L-SL	DRI
Cave Creek Cave SW/SE/24/27N/57E	9/27/65	6042	Devil's Gate Ls.	3250 v			42-44		- 2.57*	-	- 0.08*	-	- 0.35*	-		SL	HNSC
Fish Hatchery Spring NE/NE/36/27N/57E	8/24/70	5980	Devonian Devil's Gate Ls.		287	268	52	7.9	36	15	2.6	0.58	1.3	9.1	186	SL	Johnson
Bressman Spring SW/NW/18/27N/58E	8/26/70	5980	Devonian Devil's Gate Ls.	59	269	264	51	8.0	31	16	5.0	0.75	1.2	5.0	195	SL	Johnson
Spring No. 29 NW/SW/18/27N/58E	10/26/66	5900	Devonian Devil's Gate Ls.	100 E			cool		- 3.05*	-	- 0.09*	-	- 0.19*	-		SL	DRI

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (μmohs/cm)	TDS (mg/ℓ)	Temp. (F°)	pH	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)	HCO_3 (mg/ℓ)	System Class	Source of Information
X-1 Spring SE/SW/18/27N/58E	10/26/66	5900	Devonian Devil's Gate Ls.	450 E			cool		- 2.94*	-	- 0.09*	-	- 0.16*	-		SL	DRI
Nelson Spring NE/SW/4/27N/64E	9/10/66	5800		600 E			57		- 3.69*	-	- 1.67*	-	- 1.42*	-		R	DRI
Flyn Spring SW/NW/1/26N/57E	1/26/71	6160	Devil's Gate Ls.	100 E	307	288	45	7.9	49	11	3.0	0.50	1.2	5.3	207	SL	Johnson
South Stratton Spring 15/26N/62E	9/12/66	6350	Limestone	450 E			58		- 3.61*	-	- 0.18*	-	- 0.27*	-		SL	DRI
South Stratton Pond Sprg 15/26N/62E	9/12/66	6350	Paleozoic Carbonate	450 E			58		- 3.50*	-	- 0.21*	-	- 0.31*	-		SL	DRI
Aspen Spring SE/SW/10/26N/63E	9/10/66	7000	Faulted Limestone	300 E			50		- 3.43*	-	- 0.10*	-	- 0.14*	-		SL	DRI
Walti Hot Spring SW/33/24N/48E	6/17/65	5640	Devonian NV Fm.	897 E	609	(375)	160	7.1	57	12	- 70	-	14	65	315	R	USGS
--- 5/24N/44E	7/12/65				953	(524)	57	7.6	63	21	- 103	-	137	88	224	R	USGS
--- 15/26N/45E	7/12/65				806	(494)	72	7.9	54	18	- 111	-	18	95	396	R	USGS
--- 28/27N/46E	7/12/65				2330	(1411)	72	7.8	141	61	- 292	-	332	315	540	R	USGS
Twin Creek Ranch SW/SW/5/27N/56E	1/26/71	5870	Mid-Cambrian Limestone		325	314	54	7.89	52	9.5	8.2	1.4	4.3	10	210		Johnson
--- 14/25N/55E	10/22/64				572		48	7.9	53	17	28		14	105	164		USGS
--- 26/28N/61E	8/19/67			<5	360		56	8.1	39	19	- 11	-	10	26	195		USGS
Healy Ranch 11/28N/61E	8/19/67			400	330			8.0	37	16	- 11	-	7.9	19	183		USGS
Quillici Spring 2/28N/61E	8/19/67			<50	350		58	7.9	42	17	- 10	-	7.2	21	199		USGS
Twin Springs 33/27N/62E	8/19/67			10-25	360		57	8.2	44	21	- 3.0	-	4.9	13	222		USGS
Owen Springs-Paris Ranch: 33/26N/62E	8/18/67			50-100	350		50	8.0	42	19	- 9.0	-	6.2	12	220		USGS
--- 23/29N/62E	8/19/67			350+	540			8.0	62	28	- 21	-	10	62	288		USGS
Little Cedar Spring 10/35N/69E	10/22/69			70 E		630		7.8	27	10	- 193	-	187	45	263	R	USGS
Butte Spring NE/SE/17/28N/58E	8/24/70	5970	Ely Limestone	45	361	334	65	8.20	39	20	8.4	2.0	8.0	15	225	L	Johnson
Brown Ranch NE/SW/28/28N/56E	1/26/71	5900		90	346	312	50	8.05	49	8.1	17	1.4	5.4	11	220	SL	Johnson
Pearl Creek SW/SW/22/28N/56E	1/26/71	5960	Mid-Cambrian Formation	60 E	370	394	52	8.13	76	5.0	7.5	2.8	2.6	5.5	270	SL	Johnson
Belmont Spring SW/NW/27/27N/56E	8/25/70	6280	Limestone	.3	505	476	62	7.85	65	22	14	1.3	7.1	17	326	L	Johnson
Mitchell Creek (N.Fork) SE/SW/36/27N/56E	8/25/70	6920		317	453	440	53	8.15	59	28	5.7	1.1	3.0	9.1	319	SL	Johnson
Section 18 SW/NE/18/27N/58E	4/19/70	5980		25 E	268	249	45	7.89	32	16	2.5	0.5	0.92	6.2	182	SL	Johnson
South Fish NE/NE/19/27N/58E	8/24/70	5980	Pogonip Limestone	287	284	231	55	8.20	30	16	2.4	0.58	1.3	2.2	174	SL	Johnson
North Fish SE/NE/18/27N/58E	6/10/70	5980	Limestone	300 E	253	239	53	8.10	31	16	2.8	0.64	1.2	5.2	175	SL	Johnson
White Rock SE/NW/7/27N/58E	4/18/70	5980	Devonian Carbonate	5 E	285	264	54	7.78	35	16	3.0	0.98	1.4	5.2	192	SL	Johnson
Mitchell Creek (S.Fork) NW/SE/1/26N/56E	8/25/70	7440		31	482	457	45	8.0	73	22	4.5	0.70	2.2	5.0	335	SL	Johnson

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (µmohs/cm)	TDS (mg/l)	Temp. (F°)	pH	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	System Class	Source of Information
House Spring SE/SE/16/26N/56E	3/11/71	6450	Limestone		487	473	36	8.05	60	29	8.9	1.3	5.2	11	338	L	Johnson
Dames Spring NW/SE/14/26N/56E	3/11/71	6880	Carbonate		614	530	33	8.18	52	51	16	0.97	10.0	39	396	L	Johnson
Willow Creek NE/NW/33/26N/56E	8/25/70	6390		7.2	613	582	58	7.70	69	35	18	3.3	8.9	20	402	SL	Johnson
Tub Spring SE/SW/20/26N/56E	1/26/70	6130	Mid-Cambrian Limestone	9	590	572	39	7.92	58	35	27	2.0	16	27	378	R	Johnson
Walker Spring SE/SW/33/26N/56E	8/25/70	6420		3	432	398	54	8.0	47	22	14	1.1	10	14	263	L	Johnson
Buck Spring SW/NE/35/26N/56E	8/25/70	6920	Mid-Cambrian Limestone	2.1	405	374	52	7.95	59	13	11	0.46	7.7	15	252	L	Johnson
County Line North NW/SW/14/26N/57E	8/26/70	6000	Limestone	100 E	295	266	51	8.0	40	13	4.9	0.54	2.3	6.8	188	SL	Johnson
Flyn and Hager SE/NE/15/26N/57E	6/10/70	6320	Devil's Gate Ls.	221	253	250	45	7.85	46	6.5	2.4	0.54	1.2	4.1	182	SL	Johnson
County Line NE/NE/22/26N/57E	8/24/70	6000	Devonian Carbonate	21	300	276	52	7.75	38	17	3.2	0.58	2.8	6.2	201	SL	Johnson
Water Spout SE/NE/1/25N/56E	8/25/70	8000	Pogonip Limestone	9.4	304	275	49	7.8	51	7.0	4.5	0.50	2.8	6.4	195	SL	Johnson
Pete Hollum Spring SE/SW/5/25N/56E	1/26/71	6150		10	451	401	48	7.85	47	21	22	0.95	17	22	248	L	Johnson
Cherry Spring SW/SW/12/25N/56E	8/25/70	6880	Lone Mtn. Dolomite	1.8	507	459	56	7.80	42	37	18	0.96	11	31	303	L	Johnson
Upper Cherry Spring SW/NW/12/25N/56E	8/25/70	6940	Mid-Cambrian	0.28	513	460	68	7.8	49	45	16	0.75	9.5	22	340	L	Johnson
Marcise Spring NW/SW/2/25N/57E	8/24/70	6000	Pogonip Limestone	14	312	289	50	7.90	35	19	5.0	0.75	2.6	8.6	206	SL	Johnson
Cracker Johnson #2 NE/NE/31/25N/57E	8/25/70	6760		0.7	627	526	64	7.90	55	11	60	1.8	46	55	252	R	Johnson
Pilot Mountain Ranch 1/36N/69E	1/9/43			350-400													USGS
Pilot Mountain Ranch 35/37N/69E	3/13/43			30-40	110			7.4	12	3.0	-	7.0 -	6.0	5.0	53		USGS
Shiply Hot Spring NE/SE/23/24N/52E	9/18/52	5800	Devonian NV Fm.	6750	540	346	106	7.2	57	21	29	5.9	21	35	279	R	USGS
Siri Ranch Spring NW/SW/6/24N/53E	7/11/66	5800	Devonian NV Fm.	175 E			81		-	4.00* -	-	0.76* -	-	0.89* -		L	DRI
Bailey Spring SW/SW/36/24N/53E	7/11/66	5800	Silurian Lona Mtn. Dolomite	200 E			60		-	4.57* -	-	1.60* -	-	1.61* -		R	DRI
Emerald Lake Cave SE/SE/34/24N/54E	7/11/66	5960	Permian Leonardian Formation	0			66		-	4.47* -	-	1.13* -	-	1.50* -		R	DRI
Romano Artesian Spring NE/24/23N/53E	7/11/66	5800	Silurian Lone Mtn. Dolomite	100 E			61		-	3.95* -	-	1.79* -	-	1.32* -		R	DRI
Thompson Ranch Spring NW/SE/3/23N/54E	7/11/66	5840	Permian Leonardian Formation	900			71-75		-	5.03* -	-	1.14* -	-	1.47* -		R	DRI
Fad Shaft SE/NE/22/19N/53E	8/20/65	6904					cool		-	2.98* -	-	0.73* -	-	1.60* -		R-L	HNSC
Fish Creek(Sara Ranch) Springs: NW/8/16N/53E	9/29/65	6030	Devonian NV Fm.	4000	444	(277)	66	8.2	28	29	-	38 -	11	37	267	L-R	HNSC
Willow Spring NE/SE/22/26N/57E	10/26/66	6000	Miss. (?) Limestone	300 E			51		-	3.54* -	-	0.16* -	-	0.21* -		SL	DRI
Ramires Springs #2 NW/SW/27/26N/57E	10/26/66	6000	Miss. (?) Limestone	500 E			52		-	3.98* -	-	0.21* -	-	0.23* -		SL	DRI

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (µmohs/cm)	TDS (mg/l)	Temp. (F°)	pH	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	System Class	Source of Information
Ramires Springs SW/NE/34/26N/57E		6000	Miss. (?) Limestone	53		284	54		36	20	3.4	0.58	1.6	7.0		SL	Johnson
Spring No. 101 SE/SE/34/26N/57E	10/26/66	6000	Devonian Devil's Gate Fm.	225 E			52		- 3.42* -		- 0.22* -		- 0.26* -			SL	DRI
Indian Creek Spring SE/NW/20/26N/64E	7/14/66	6800	Pogonip Group (?) Limestone	150 E			61		- 4.50* -		- 0.26* -		- 1.00* -			L	DRI
Headwaters Spring SW/SE/34/25N/55E	10/24/64	6040	Ely Limestone	670 E	361		63	7.6	52	9.6	9.2		7.9	17	196	L	USGS
Pony Express Spring SW/13/25N/57E	10/26/66	6000		200 E			52		- 4.02* -		- 0.33* -		- 0.41* -			L	DRI
Goshute Creek 12/25N/63E	7/14/66	6400	Limestone	400 V			66		- 3.86* -		- 0.20* -		- 0.42* -				DRI
Chin Spring NE/SW/27/25N/67E	9/10/66	7000	Volcanics &/or Ls.	100 E			cool		- 4.49* -		- 0.56* -		- 0.90* -			L	DRI
Cold Spring SW/SW/26/23N/67E	7/12/66	6120	Permian Limestone	200 E			56		- 2.95* -		- 0.58* -		- 0.52* -			L	DRI
Tippet Warm Spring NE/NW/14/23N/67E	9/9/66	6000	Limestone	150 E			67-70 E		- 5.28* -		- 0.36* -		- 0.81* -			L	DRI
Goicoechea Ranch Spring NW/SW/11/22N/55E	7/12/66	5860	Permian Limestone	400 E			62		- 2.41* -		- 0.23* -		- 0.31* -			SL	DRI
Minoletti Spring NE/NW/11/22N/55E	/12/66	5860	Permian Limestone	425 E			60		- 3.01* -		- 0.37* -		- 0.54* -			L	DRI
Giocoechea (Simonson) Warm Sprg: NE/NE/1/22N/56E	10/25/66	5880	Devonian Guilmetti Fm.	1120 R			74-76		- 4.06* -		- 0.96* -		- 0.91* -			L	DRI
John Borchert Spring NE/16/22N/63E	9/29/65	6200	Cambrian Limestone	447			64		- 3.51* -		- 0.26* -		- 0.48* -			L	HNSC
Lower Schellbourne Cold Spring: 1/22N/64E	9/11/66	7000	Limestone	100 E			54		- 4.42* -		- 0.45* -		- 0.70* -			L	DRI
Lower Schellbourne Warm Spring: 12/22N/64E	9/11/66	7000	Limestone	450 E			77		- 4.22* -		- 0.36* -		- 0.37* -			L	DRI
Upper Schellbourn Warm Spring: SE/NW/8/22N/65E	9/11/66	7200	Limestone	450 E			73		- 4.43* -		- 0.17* -		- 0.54* -			L-SL	DRI
Deadman Spring SW/NW/25/21N/63E	7/12/66	6480	Pennsylvanian Moleen Fm.	175 E			52		- 2.60* -		- 0.38* -		- 0.52* -			L	DRI
Monta Neva Hot Spring NE/NW/25/21N/63E	10/27/66	6030	Ord.-Sil.-Dev. Carb.	630			174		- 4.76* -		- 0.72* -		- 0.68* -			L	DRI
Thirty Mile Spring-Uhalde Ranch: 33/20N/60E	8/15/67			40-50	230		48	7.7	26	5.1	- 16 -		6.9	8.7	124		USGS
Nine Mile Spring 21/22N/62E	8/21/67			<10	420		51	7.6	58	6.4	- 22 -		16	24	210		USGS
--- 5/19N/63E	10/8/65				300			7.9	21	22	- 18 -		5.2	27	178		USGS
Eureka Water System Spl. 19N/53E	1/13/72					286		8.29	63	16	- 15 -		9.0	40	234		NSHS
Mountain Side Spring 18/19N/44E	2/13/61					451		8.11	48	5.9	- 10 -		10	28			NSHS
Big Creek Mining-Milling 19/19N/44E	11/22/65					834		7.2	179	40	- 94 -		35	360	476	R	NSHS
Austin 20/19N/44E	3/28/72					189		8.08	37	7.0	- 17 -		11	24	139		NSHS
Lander Co. Sewer-Water 29/19N/44E	4/10/69					183		7.77	35	7.8	- 17 -		8.0	24	146		DRI
Marshall Canyon Tunnel 30/19N/44E	9/7/65					338		7.32	57	20	- 31 -		24	67	232	R	NSHS

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (μmohs/cm)	TDS (mg/ℓ)	Temp. (F°)	pH	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)	HCO_3 (mg/ℓ)	System Class	Source of Information
SE Battle Mountain 30N/45E	5/28/63					750		7.15	59	69	-	34 -	2.0	226	149	R	NSHS
Mastroianni 36/32N/44E	4/9/69					414		7.66	69	15	-	42 -	45	102	193	R	NSHS
6 mile north of McGill 19N/63E	9/6/17					320					-	60 -	6.2	21	257		USGS
2 mile north of McGill 3/18/64E	3/30/18					240					-	24 -	9.4	27	147		USGS
6 mile NW of McGill 5/19N/63E	4/9/18					268			52	21	-	15 -	4.5	20	268		USGS
17 mile north of McGill 21N/64E	8/21/17					349			67	21	-	26 -	6.6	25	324		USGS
Indian Spring SE/SW/10/21N/70E	9/9/66	7000	Cambrian Limestone	100 E			cool		-	1.61* -	-	0.79* -	-	1.04* -		L	DRI
Pleasant Valley Spring SE/NE/21/21N/70E	9/9/66	6000	Cambrian Limestone	100 E			cool		-	5.36* -	-	1.02* -	-	1.53* -		R	DRI
Robinson Springs 5-8/20N/55E	7/12/66	6960	Carboniferous Carbonate	175 E			60		-	2.20* -	-	0.11* -	-	0.36* -		SL	DRI
North Group Springs 5/19N/63E	<1920	6100	Hamburg Limestone	450(?)			77		-	4.33* -	-	0.65* -	-	0.53* -		L	USGS
Gallagher Gap Spring SW/NE/3/18N/64E	5/21/66	6480	Devonian Limestone	337 E			cool		-	3.86* -	-	0.69* -	-	0.28* -		L	DRI
Schoolhouse Spring NW/SE/3/18N/64E	5/21/66	6280	Mid-Cambrian Raiff Ls.	450(?)			76		-	3.51* -	-	0.58* -	-	0.74* -		L	DRI
McGill (Warm) Spring SE/NE/3/18N/65E	9/29/65	6640	Mid-Cambrian Raiff Ls.	4578			76-84		-	5.11* -	-	1.01* -	-	3.34* -		R	HNSC
--- 27/22N/49E	5/19/64				280			8.2	26	6.3	23		10	18	132		USGS
--- 36/22N/48E	5/19/64				186			7.8	16	4.4	17		6.0	19	80		USGS
--- 20/18N/47E	4/14/64				579	(321)		7.8	62	12	36		43	88	160	R	USGS
--- 7/38N/56E	8/11/77			0.35	470		55	7.75									LLL
--- 2/38N/56E	1977			1	460		53	7.15									LLL
--- 33/30N/69E	7/15/77			4	430		61	7.3									LLL
--- 36/20N/54E	9/10/77			1	300		60	7.3									LLL
--- 33/20N/54E				75	190		50	7.1									LLL
--- 28/20N/54E	9/11/77			2	310		48	7.1									LLL
--- 19/25N/53E	9/12/77			1.5	380		54	7.3									LLL
--- 7/25N/53E	9/12/77			1	390		55	7.2									LLL
--- 24/22N/50E	9/13/77			3	345		49	7.2									LLL
--- 23/22N/50E	9/13/77			5	300		46	7.2									LLL
--- 26/22N/50E	9/13/77			10	360		50	7.3									LLL
--- 8/23N/51E	9/14/77			3	470		54	7.3									LLL

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (µmohs/cm)	TDS (mg/l)	Temp. (F°)	pH	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	System Class	Source of Information
--- 35/23N/50E	9/14/77			5.0	325		51	7.2									LLL
--- 22/23N/49E	9/14/77			0.3	480		56	7.1									LLL
--- 25/23N/54E	9/12/77			2	225		53	7.2									LLL
--- 26/25N/54E	9/12/77			0.3	235		48	7.1									LLL
--- 18N/53E	10/10/77			3	360		51	7.3									LLL
--- 24/15N/50E	9/22/77			2	250		49	7.7									LLL
--- 19/14N/47E	9/24/77			15	370		59	7.8									LLL
Bird Creek Spring SE/NE/3/18N/65E	5/7/66	7760	Dunderberg(?) & Windfall Formations	718					-	3.10* -	-	0.16* -	-	0.24* -		SL	DRI
South Mulick Spring NE/SW/25/17N/67E	7/12/66	5600	Carbonate	200 E			55		-	4.32* -	-	0.48* -	-	0.51* -		L	DRI
Illipah Spring SE/SW/10/16N/58E	8/18/66	7560	Pennsylvanian Ely Ls.	900 E			cool		-	2.61* -	-	0.26* -	-	0.18* -		SL	HNSC
Eberhardt Tunnel NW/SE/31/16N/58E	11/11/66	7680	Devonian NV Ls.	0			47		-	3.25* -	-	0.29* -	-	0.62* -		SL	HNSC
Murry Springs SE/SE/20/16N/63E	12/11/51	6640	Ely Limestone	3300	374		55	7.6	49	18	3.5	0.7	1.3	9.8	232	SL	USGS
Green Springs SE/SW/33/15N/57E	8/19/65	6080	Nevada Limestone	675			63		-	4.06* -	-	0.43* -	-	0.62* -		L	DRI
Cave Springs SE/NW/10/15N/65E	5/21/66	7600	Guilmette Formation	300 E			cool		-	3.32* -	-	0.06* -	-	0.14* -		SL	DRI
Bastian Spring SW/NE/21/15N/66E	7/13/66	6640	Lincoln Peak & Windfall Fm.	150 E			53		-	2.78* -	-	0.10* -	-	0.17* -		SL	DRI
Big Bull Spring SE/SE/14/14N/56E	11/12/66	5800	Ely Limestone	400	365		54		-	2.91* -	-	0.55* -	-	0.61* -		L	DRI
Bull Creek Spring SE/NW/25/14N/56E	11/12/66	5800	Ely Limestone	225			54		-	2.30* -	-	0.80* -	-	0.78* -		L	DRI
Big Smoky Valley 22/15N/44E	9/22/13					302			73	24	-	3.1 -	9.0	41	283		USGS
Willow Spring Illipah Quad: 10/18N/59E	6/12/73					266		7.29	47	8	-	21 -	12	19	183		NSHS
27 mile SE of Ely 12N/65E	7/5/18					214			44	17	-	7 -	7.2	22	197		USGS
Kennecott Copper Corp. 10/16N/62E	7/7/66					975								480			NSHS
1 mile NE of Ely 10/16N/63E	4/10/18					314			51	23	-	19 -	7.5	68	222		USGS
Pine Spring 22/14N/51E		7400		449													USGS
Indian Spring 4/14N/51E		8600		22													USGS
--- 9/16N/53E	8/29/65	6100	Limestone		462	(298)	64	8.2	37	29	-	36 -	8.6	51	273	R	USGS
Willow Creek Springs NE/NW/35/14N/63E	10/28/66	7200-7640	L. Permian Arcturus Fm.	685			55		-	3.47* -	-	0.09* -	-	0.51* -		SL	DRI
Water Canyon Springs NW/8/13N/63E	10/28/66	7600-7680	Ely Limestone	325 V			48		-	3.59* -	-	0.09* -	-	0.14* -		SL	DRI
Rowland Spring SE/NE/10/13N/69E	9/30/66	6300	Pole Canyon Ls.(Cambrian)	1900			48		-	1.46* -	-	0.30* -	-	0.36* -		L-SL	HNSC

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (µmohs/cm)	TDS (mg/l)	Temp. (F°)	pH	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	System Class	Source of Information
Preston Big Spring NW/NE/2/12N/61E	11/13/66	5700	Carbonate	3900			70		- 3.17*	-	- 0.64*	-	- 1.18*	-		L	DRI
Cold Spring SW/NW/12/12N/61E	11/13/66	5700	Carbonate	780			70		- 3.47*	-	- 0.65*	-	- 1.15*	-		L	DRI
Nicholas Spring SE/12/12N/61E	11/13/66	5700	Carbonate	1125			71		- 3.00*	-	- 0.66*	-	- 1.31*	-		L	DRI
Arnoldson Spring SW/SE/12/12N/61E	11/13/66	5700	Carbonate	1380			72		- 2.98*	-	- 0.66*	-	- 1.28*	-		L	DRI
Mount Wheeler Mine NW/SW/15/12N/68E	10/28/66	7960	Wheeler Limestone	36			45		- 2.96*	-	- 0.05*	-	- 0.23*	-		SL	DRI
Spring Creek Spring NW/SW/15/12N/70E	7/13/66	6120	Ord.-Sil.-Dev. Carb.	713-1683 V			54-56		- 3.84*	-	- 0.31*	-	- 0.49*	-		SL	DRI
Lund Spring NE/NE/1/11N/62E	6/15/66	5600	Ely Limestone	2800			66		- 4.35*	-	- 0.21*	-	- 0.32*	-		SL	DRI
Shoshone Springs SE/SW/1/11N/67E	10/29/66	5800	Pole Canyon Limestone	300 E			53									SL	DRI
Ely Ragsdale Spring 6/17N/63E	4/6/18					450					- 56	-	18	28	365	R	DRI
Div. of Water Resources 6/23N/63E	9/19/67					550		7.5	19	1.0	- 146	-	18	9.6	407		NSHS
Cherry Creek 30/24N/63E	11/22/71					147		7.26	32	10	- 2.0	-	4.0	19	120		NSHS
D Bar X 21/15N/68E	7/15/71					293		7.58	80	15	- 20	-	13	13	329		NSHS
Kennecott Cooper Corp. 23/15N/62E	6/20/66					199		7.9	49	13	- 12	-	4.0	28	195		NSHS
Circle Wash 32/15N/59E	6/11/73					140		7.68	20	6.0	- 19	-	4.0	12	100		NSHS
25 mile NW of McGill 22N/61	5/22/18					231			47	19	- 4.4	-	3.5	13	227		USGS
Healeys Park Round Mtn. 13/10N/44E	5/23/73					167		8.11	35	5	18	1.0	5.0	20	153		NSHS
--- 33/10N/70E	11/3/64					216		7.8	47	20	- 5.9	-	3.7	8.0	238		USGS
Cave Sp outside Monument 9/13N/69E	9/27/71					46		7.61	16	3	- 4.0	-	8.0	3.0	56		NSHS
Minerva Spring NE/SE/12/11N/67E	10/29/66	6400	Pole Canyon Limestone	300 E			53		- 3.30*	-	- 0.16*	-	- 0.22*	-		SL	DRI
Swallow Canyon Spring SW/4/11N/68E	7/12/66	6400	Pole Canyon Limestone	0-1800			49		- 3.41*	-	- 0.06*	-	- 0.25*	-		SL	DRI
Spring NE/NW/5/11N/68E	7/12/66	6080	Pole Canyon Limestone	275 E			49		- 3.14*	-	- 0.06*	-	- 0.22*	-		SL	DRI
Six Mile Springs NE/NE/4/10N/62E	11/14/66	5650	Ord.-Sil.-Dev. Carb.	175			61		- 4.87*	-	- 0.31*	-	- 0.26*	-		SL-L	DRI
Big Spring 33/10N/70E	9/30/65	5550	Ord.-Sil.-Dev. Carb.	4000			61		- 3.33*	-	- 0.29*	-	- 0.29*	-		SL-L	HNSC
Big Warm Spring SE/NW/32/13N/56E	4/16/63	5600	Devil's Gate Ls.	6300	587	(335)	90	8.0	62	22	28	6.5	8.6	47	321	R	USGS
Little Warm Spring NW/NW/5/12N/56E	11/12/66	5600	Devil's Gate Ls.	300 E	704	(403)	90	8.0	39	25	- 83	-	10	62	368	R	USGS
Current Spring SE/SW/18/12N/59E	11/13/66	7700	Devonian Limestone	150			47		- 3.61*	-	- 0.21*	-	- 0.22*	-		SL	DRI
West Immigrant (Hardy) SW/13/9N/61E	11/14/66	5350	Ordovician Carbonate	200 E			66		- 4.62*	-	- 0.33*	-	- 0.42*	-		L	DRI
Morman Spring SW/32/9N/61E	11/15/66	5300	Limestone	1900		(323)	98-100		68	32	- 23	-	8.9	46	290	R	DRI

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (μmohs/cm)	TDS (mg/ℓ)	Temp. (F°)	pH	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)	HCO_3 (mg/ℓ)	System Class	Source of Information
Big Spring 33/10N/70E		5580		3590 E	401	216	64	7.8	47	20	- 5.9	-	3.7	8.0	238		USGS
--- 27/9N/67E	7/15/64				236		70	7.9	24	6.8	- 18	-	11	11	122		USGS
Belmont 26/9N/45E	5/23/73					239		8.13	54	11	10	1.0	3.0	18	197	L	DRI
Ducan Ranch Hot Creek Canyon: 25/8N/49E	4/24/72					428		7.62	72	22	- 48	-	19	52	361	R	NSHS
Butterfield Springs 28/7N/62E	1/1/44					283			40	23	- 2.0	-	18	27	178		DRI
--- 24/8N/49E	8/29/65				462	284	92	8.0	18	26	- 52	-	22	64	204	R	USGS
--- 29/8N/50E	8/30/65				718	447	94	8.2	13	26	- 124	-	33	81	340	R	USGS
Immigrant Spring SW/NE/19/9N/62E	7/31/75	5450	Ord.-Sil.-Dev. Carb.	1350	425	370	67	6.8	88	35	41	6.0	84	107		SL-L	DRI
Lockes Stockyard Spring NE/NE/15/8N/55E	11/12/66	4860	Devonian NV Fm.	425 E			89-93		- 4.74*	-	- 2.55*	-	- 1.57*	-		R	DRI
Reynolds Spring SE/NE/15/8N/55E	11/12/66	4860	Nevada Formation	323			97-99		- 4.65*	-	- 2.45*	-	- 1.58*	-		R	DRI
Blue Eagle & Jack's Spring: SE/SE/11/8N/57E	11/12/66	4760	Devonian Carbonate	2270 V		590	82		80	24	- 30	-	10	34	385	R	NSS
Tom Spring NW/NW/12/8N/57E	11/12/66	4760	Devonian Carbonate	250 E			71		- 5.20*	-	- 1.77*	-	- 0.99*	-		R	DRI
Butterfield Spring NE/SE/27/8N/57E	11/13/66	4750	Devonian Carbonate	200 E			61		- 4.81*	-	- 1.70*	-	- 0.99*	-		R	DRI
Butterfield Springs NW/NE/28/7N/62E	11/14/66	5250	Ord.-Sil. Carbonate	1125					- 3.98*	-	- 0.34*	-	- 0.36*	-		L	DRI
Flag Springs SW/NW/33/7N/62E	7/6/75	5250	Fish Haven Dolomite	1125	405	350	64	7.5	50	20	8.0	2.0	27	11		L	DRI
Forest Home Spring NE/SE/18/6N/59E	11/14/66	6210	Paleozoic Carbonate	425 E			57		- 4.81*	-	- 0.42*	-	- 0.61*	-		L	DRI
Moon River Spring NW/25/6N/60E	11/14/66	5200	Lehman Fm. of Pogonip Group	900			92		- 4.26*	-	- 1.23*	-	- 1.10*	-		R	DRI
Hot Creek Springs SE/NE/18/6N/61E	5/27/49	5200	Silurian Lake-town Dolomite	6885		346	92		58	22	- 32	-	12	45	294	R	NSS
Cave Spring 16/9N/64E	5/24/66	6500	Pole Canyon Limestone	400 V			cool		- 0.77*	-	- 0.12*	-	- 0.22*	-		SL	DRI
Geyser Spring SW4/9N/65E	8/7/63	6800	Pole Canyon Limestone	58-1153		115	68	8.0	30	3.4	0.2	1.0	3.0	5.0	103	SL	USGS
Franks Warm Springs 20/4N/50E	5/23/73					819		8.27	67	24	156	32	30	105	642	R	NSHS
Willow Spring 36/2S/43E		5950		<1.0													USGS
Stonewall Spring 5/5S/44E		5800		10	282		69										USGS
Staininger's Springs 6/11S/43E	1/20/67	3200		200	734	(419)	77	8.1	9.6	2.4	- 149	-	47	92	238	R	USGS
Grapevine Springs 6/11S/43E		2800		>20													USGS
Summer Spring 17/2S/51E		6700		3.0													USGS
Cedar Spring 21/2S/51E	8/1/67	6540		2.5	533	(346)	77	7.7	62	5.9	47	2.5	23	48	240	R	USGS
Storm Spring 11/6N/54E	10/7/71	4805		5.0	1200		98						17				USGS

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (μmhos/cm)	TDS (mg/ℓ)	Temp. (F°)	pH	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)	HCO_3 (mg/ℓ)	System Class	Source of Information
Crows Nest 27/6N/56E	8/7/67	4755			391		56						3.3				USGS
Willow Spring 5/6N/57E	2/7/34	4750		30			60										USGS
Thorn Spring 28/7N/57E	10/13/71	4750		50-100	686	(353)		7.8	57	33	- 35	-	14	25	378	R	USGS
Snow (Crystal) Spring 15/11N/58E		6380		1-5.0													USGS
Pastroni Spring 32/11N/58E	10/12/71	5360		300	432		55		36	22	- 20	-	11	19	230		USGS
Bull Creek 25/14N/56E		5790		225			54										USGS
Birch Spring 22/14N/57E	11/5/70	6250		5-10	574		46		62	21	- 26	-	24	38	272		USGS
Green Spring 33/15N/57E	11/5/70	6080		>100	488		63										USGS
Panaca Warm Spring NW/NE/4/2S/68E	5/22/66	4760	Highland Peak Limestone (Mid-Cambrian)	3600-4883	401	(229)	85-88	8.1	31	9.8	- 44	-	15	29	189	R	NSS
Hiko Spring 22/4S/60E	3/10/62	3890	Simonson Dolomite Mid-Devonian	2400		(445)	80	8.0	44	23	29	7.0	11	36	251	R	DRI
Crystal Spring NE/10/5S/60E	4/15/63	3840	Devonian Limestone	5300		(400)	82	8.3	45	24	30	5.0	10	44	246	L-R	NSHD
Brownie Spring NE/26/5S/60E	5/23/66	3700	Devonian Carbonate	50 E			warm		-	3.72* -	-	2.10* -	-	1.02* -		R	DRI
Ash Spring SE/SE/36/5S/60E	5/23/66	3610	Sevy Dol. (Devonian)	7630		(418)	90	7.8	56	14	33		10	35	264	R	NSHD
Warm (Muddy) Spring 16/14S/65E	4/15/63	1760	Bird Spring Formation	3236	1045	720	90	8.0	65	29	101	10	61	193		R	BLM
Iversön (Warm) Spring NE/NE/21/14S/65E	9/12/63	1760	Bird Spring Formation	1696	964	620	89	7.5	70	26	101	11	64	179	274	R	USGS
Fairbanks Spring SE/NE/9/17S/50E	10/27/64	2280	Cambrian Limestone	1715	686	552	80	7.3	51	18	71	8.0	22	80	300	R	USGS
Rogers Spring NW/NE/15/17S/50E	10/7/71	2260	Cambrian Limestone	717-736	693	571	82-84	8.0			55	14	26	96	290	R	USBR
Longstreet Spring NW/NE/22/17S/50E	10/28/64	2300	Nopah Fm. (Cambrian)	1042-1239	681	549	80-82	7.4	51	17	68	7.9	22	78	303	R	USGS
Devil's Hole SW/SE/36/17S/50E	6/28/72	2400	Bonanza King Fm. (Cambrian)	0	707	557	92	7.5	48	20	69	7.5	26	81	304	R	DRI
Crystal Pool SE/NE/3/18S/50E	12/30/71	2180	Bonanza King Formation	2824	657	593	89-91		48	20	80	8.8	31	92	311	R	DRI
Point-of-Rock (King) Spirng: SE/NW/7/18S/51E	10/4/70	2250	Bonanza King Formation	1162	625	521	89-90	7.9	45	19	70	8.0	20	79	278	R	USGS
Big Spring SW/NE/19/18S/51E	1/27/59	2240	Bonanza King Formation	1078-1247	780	(471)	83	7.17	45	18	98	8.8	25	110	314	R	USGS
Bennetts Springs SW/SE/14/20S/53E	8/5/27	2680	Bird Spring Formation	0 was 2520		358	76		50	22	- 8.2	-	0.7	33	244	L	NSS
Manse Springs 3/21S/54E	8/5/27	2800	Bird Spring Formation	605		268	75		55	29			4.9	42	239	R	NSS
Indian Springs NW/NW/16/16S/55E	10/23/64	3200	Bird Spring Formation	408	401	335	78	7.4	50	20	4.5	1.1	3.7	16	238	R	USGS
Willow Spring SW/NE/2/18S/55E	8/2/65	6000	Paleozoic Carbonate	225			54		-	3.60* -	0.35*		-	0.38* -		L-SL	NSDH
Rogers Spring SE/SE/12/18S/67E	1/31/66	1600	Miss. Limestone	880	3750	3020	80	7.3	443	140	- 395	-	334	1680	166	R	NSDH

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (µmohs/cm)	TDS (mg/l)	Temp. (F°)	pH	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	SO_4 (mg/l)	HCO_3 (mg/l)	System Class	Source of Information
Blue Point Spring SW/SE/6/18S/68E	11/27/45	1520	Miss. Limestone	400 E		3300	80		472	167	- 317	-	355	1910	122	R	NSDH
Deer Creek Springs 18/19S/57E	8/28/65	8600	Cambrian Carb. & Ord. Carb.	140			42-44		-	4.16* -	0.17*		-	0.26* -		SL	NSDH
Intermittent Spring SE/31/20S/56E	8/24/16	4640	Cambrian Ls. & Dol.	450-1500			57		-	4.92* -	0.17*		-	0.60* -		L	USGS
Las Vegas Springs 30/20S/61E	11/2/51		Paleozoic Carbonate				73									L	USGS
--- 2/15S/70E	7/17/46					606			89	30	- 83	-	52	143	371	R	USGS
--- 2/15S/70E	7/17/46					550			85	28	- 77	-	40	84	390	R	USGS
--- 14/15S/70E	5/31/35					539			84	19	- 83	-	33	116	366	R	USGS
--- 4/15S/71E	10/10/49					461			89	31	- 33	-	18	58	408	R	USGS
Bitter Spring 16/19S/67E	11/13/67				4100	3670	64	7.6	601	189	- 251	-	178	2360	141	R	USGS
Spring-Greasewood Basin 22/16S/71E	11/11/67				490	290	63	7.6	54	31	- 4	-	8.0	10	303		USGS
Angel Spring 20/16S/68E	1/31/66				2430	1740		7.4	146	102	261	21	186	834	251	R	USGS
Fleur-de-Lis Ranch 14/10S/47E	3/14/62			50	550	384	72	8.5	6.0	1.0	- 117	-	54	24	212	R	USGS
Springdale Ranch 30/10S/47E	3/14/62			25	680	477	58	8.1	27	4.9	- 105	-	48	14	278	R	USGS
Campbell 33/10S/47E	3/14/62			15	760	532	75	8.0	24	0.1	- 127	-	1.9	65	275	R	USGS
Currie Well 22/11S/45E	3/15/62			0.25	500	352		7.6	42	9.8	- 60	-	68	38	155	R	USGS
Upper Indian Springs 26/11S/46E	2/22/56				319	224	60	7.9	8	1.0	62	2.0	16	22	131	R	USGS
--- 4/11S/47E	3/14/62			7	760	532	65	8.4	27	4.9	- 126	-	52	29	310	R	USGS
Torrance 9/11S/47E	3/14/62			10	1000	712	59	8.0	24	5.8	- 177	-	78	34	383	R	USGS
Goss Springs 10/11S/47E	3/14/62			50-75	590	413	71	8.3	19	1.0	- 90	-	48	24	188	R	USGS
Hot Springs 16/11S/47E	3/14/62			5	750	526	97	7.9	18	0.5	- 144	-	48	72	266	R	USGS
Rancho Truabq 21/11S/47E	3/14/62			100	1100	784	97	7.9	27	3.9	- 181	-	75	48	393	R	USGS
Circle C Ranch 33/11S/47E	3/14/62			25	470	330	88	8.4	4.8	0.5	- 96	-	31	34	176	R	USGS
Beatty Municipal Springs: 5/12S/47E	2/22/56			100	552	368	76	8.2	14	1.9	106	5.8	27	69	194	R	USGS
Bell Soda 10/17S/50E	7/31/62			79	650		73										USGS
Bole Spring 30/18S/51E	7/27/62			12	776	500	72	7.1	38	19	106	9.2	27	113	306	R	USGS
Bonnie Springs 19/22S/58E	5/26/67					382		7.72	73	42	- 10	-	13	62	224		Private
Blue Diamond R. 21/22S/60E	3/9/72					599		7.74	98	48	- 1.0	-	10	207	264		NSHS
Warm Springs 4/22S/61E	12/3/69					701		7.95	115	55	- 15	-	13	352	195	R	NSHS

APPENDIX II (cont.)

Name & Location	Date	Elevation (ft.)	Lithologic Unit	Discharge (gpm)	SpC (µmohs/cm)	TDS (mg/ℓ)	Temp. (F°)	pH	Ca (mg/ℓ)	Mg (mg/ℓ)	Na (mg/ℓ)	K (mg/ℓ)	Cl (mg/ℓ)	SO_4 (mg/ℓ)	HCO_3 (mg/ℓ)	System Class	Source of Information
Whitney Mesa Spring /22S/62	8/1/73							7.78	606	294	690	6.0	1287	2212	188	R	DRI
Lockes Big Spring SW/NE/15/8N/55E	11/12/66	4860	Nevada Formation	520			99-101		-	4.70* -	-	2.43* -	-	1.56* -		R	DRI
Shingle Spring 19/8N/63E	7/31/75			4	505	405	65	7.5	60	19	15	2.0	18	24			BLM
White River Valley Spring: 17/6N/59E	7/26/75			21	485	395	58	7.6	56	26	10	1.0	9.0	19			BLM
Highland Spring 26/1N/66E	7/25/75			3.5	515	430	58	7.2	60	34	2.0	0.5	12	3.0			BLM
Kane Springs Wash 21/9S/65E	7/17/75			2.4	180	130	87	7.9	19	4.0	10	2.0	0.5	9.0			BLM
Mormon Well Spring 24/15S/61E	6/27/75			3.7 E	710	590	59	8.0	75	40	10	1.0	17	22			BLM

APPENDIX II (cont.)

APPENDIX III

Cave Lengths and Lithologic Units*

County	Name	Elevation (ft.)	Length (ft.)	Lithologic Unit
Clark	Bristlecone Bridge Cave	8960	127	Ordovician Carbonates
	Column Cave	8160	100	Monte Cristo Limestone
	Desert Cave	4080	284	Kaibab Limestone
	Gypsum Cave	1921	300	Kaibab Limestone
	Moms Cave	8000	186	Monte Cristo Limestone
	Pinnacle Cave	5920	100	Sultan Limestone or Goodsprings Dolomite
	Robbers Roost Cave	8080	100	Sultan Limestone or Monte Cristo Limestone
	Salt Cave #1	1300	478	Muddy Creek Formation
	Soda Straw Cavern	8435	761	Ordovician or Cambrian Limestone
	Trout Spring Cave		3000	Mississippian, Pennsylvanian, or Permian Carbonates
	White Bluff Cave	1840	150	Muddy Creek Formation
	Yewas Cave	2000	137	
Elko	Angel Lake Pit	7440	180	
	Bronco Charlie Cave	7000	150	Devil's Gate Limestone
	Cave Creek Cave	6080	500	Devil's Gate Limestone
	Cirque Cave	9320	105	Devil's Gate Limestone
	Dead Tree Cave	6800	175	Devil's Gate Limestone
	Lost Hope Cave	8720	206	Joana Limestone
	Quill Cave	6800	304	Devil's Gate Limestone
	Twin Pits	9200	109	Devil's Gate Limestone
Eureka	Emerald Lake Cave	5960	181	Permian Carbonates
	Jumbo Cave	7700	150	Cambrian Dolomite
	Mill Hole Cave	8000	150	Wenban Limestone
	Mineral Hill Cave	6700	150	Devonian Carbonates
Lander	Iron Canyon Mine Cave	5805	270	Scott Canyon Formation
Lincoln	Cave on Highland Peak	7600	110	Pioche or Windfall (Cambrian)
	Cave Valley Cave	6470	3000	Pole Canyon Limestone
	Henries Cave	6100	216	Devonian to Cambrian Carbonates
	Lavender Cave	6500	152	Gulmette Formation - Sevy Dolomite

County	Name	Elevation (ft.)	Length (ft.)	Lithologic Unit
	Leviathan Cave	7800	1400	Gulmette Formation
	Snowslide Cave	6800	368	Upper Cambrian
	Whipple Cave	6240	800	Whipple Cave Formation
Nye	Devil's Hole	2430	400	Upper Division of Bonanza King Formation
	Devil's Hole Cave	2500	130	Upper Division of Bonanza King Formation
	Hot Creek Cave	6060	105	Pogonip Group
	Manhatten Consolidated Mine - Cave	7425	300	White Caps Limestone of Gold Hills Formation
	Northumberland Cave	8200	855	Pogonip Group
	Owen City Cave	6100	239	Nopah Formation
	Uhalde Pit Cave	6400	100	Simonsen Dolomite
Pershing	Bell Cave	8800	526	Natchez Pass Formation Star Peak Group
	Snow White Cave	4920	270	Triassic
	Star Peak Cave	8920	1200+	Natchez Pass Formation Star Peak Group
White Pine	Amberat Cave	6200	117	Middle Cambrian
	Bristlecone Cave	10280	186	Pole Canyon Limestone
	Burial Cave	5660	250	Gulmette Formation
	Cathedral Cave	7000	602	Middle Cambrian Limestone
	Cave on Cave Creek	7440	102	Joana Limestone
	Cave of the Birds	8100	130	Middle Cambrian
	Cave of the Council Hall	6600	200	Middle Cambrian
	Christmas Tree Cave	7000	126	Whipple Cave Formation Upper Cambrian
	Crevasse Cave	7100	300	Pole Canyon Limestone
	Dads Hole	7000	286	Whipple Cave Formation
	Deep Cave	7120		Pole Canyon Limestone
	Dome Ice Cave	11120		House Limestone
	Lexington (Forgotten) Cave	7240	1000	Notch Peak and Lincoln Peak Limestone
	Goshute Cave	6800	1000+	Upper Cambrian or Ordovician
	Hallidays Deep Cave	7100		
	Highland Cave	11120		Pole Canyon Limestone and House Limestone

County	Name	Elevation (ft.)	Length (ft.)	Lithologic Unit
	Ice Cave	7080		Pole Canyon Limestone
	Ladder Cave	7000	200	Middle Cambrian
	Last Chance Cave	8160	105	Upper or Middle Cambrian Carbonates
	Lehman Annex Cave	7200	700	Pole Canyon Limestone
	Lehman Caves	6825	10000	Pole Canyon Limestone
	Model Cave	6920		Pole Canyon Limestone
	Monument Cave	9000	790	Middle Cambrian Carbonates
	Old Man Cave	7000	1427	Middle Cambrian Carbonates
	Osceola Tunnel	7300	200	Pogonip Group
	Pescio Cave	7800	470	Middle or Upper Cambrian Limestone
	Ragged Cave	7680	290	Middle or Upper Cambrian Carbonates
	Rat Cave	6800	236	Ordovician or Upper Cambrian Carbonates
	Robust Mine Cave	6800	400	Nevada Limestone
	Rockslide Cave	6800	105	Middle Cambrian Carbonates
	Root Cave	6887	200	Pole Canyon Limestone
	Rose Guano Cave	6700	483	Pogonip Group
	Rudolph's Cave	6280	103	Notch Peak Limestone
	Sacramento Pass Cave	7000	100	Ordovician or Upper Cambrian Limestone
	Snake Canyon Cave	9120	350	Pogonip Group
	Snake Creek Cave	6600	1000+	Notch Peak Limestone
	Systems Key	7040	779	Pole Canyon Limestone
	Travertine Cave	8100	187	Middle Cambrian Limestone
	Water Canyon Cave	6600	175	
	Yorks Guano Cave	7000	185	Ordovician or Upper Cambrian Limestone

* (From McLane, 1972)

APPENDIX IV

Wildcat Oil and Gas Wells

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Clark County							
Sec22 T22S R60E	2561	-1274	3835	6759	Miss. (Monte Cristo gr ?)	2929	circulation problems @2993', fresh water @3600'
Sec31 T21S R60E	2900	200	2700	3260	Penn. (?)(Callville Limestone?)	560	circulation problems @634', DST @3055 - recovered 2700' fresh water in 1 hour
Sec31 T21S R60E	2750	1775	975	1897	Bird Spring Fm.	922	
Sec10 T22S R60E	2560	none	1627	1627	none		
Sec9 T22S R60E	2650	270	2380	5686	Bird Spring Fm.	3306	water @2850-2900', 2940-3030', 3090-3530'
Sec20 T22S R60E	2631	1107	1524	3767	Bird Spring Fm.	2243	
Sec24 T21S R61E	2100	-2375	4475	8508	Kaibab Limestone	4033	water @5014-5206', well complt 137°F fresh artesian 400 B/hr
Sec18 T17S R65E	2122			5085	no log		
Sec18 T17S R65E	2090			3496	no log		
Sec23 T23S R59E	3700	2600	1100	3293	Miss. (Monte Cristo gr ?)	2193	lost circulation @2165', 3293'
Sec1 T25S R59E	2850	1465	1385	2273	Kaibab Limestone	888	
Sec4 T20S R59E	3860			1725	no log		lost circulation @1047', water flow 1668-1678'
Sec35 T15S R65E	1800			1625	no log		
Sec7 T20S R65E	2304	-2199	4503	5666	Kaibab Limestone	1163	fresh water @3930-4030'
Sec5 T20S R66E	2042	-1678	3720	5919	Callville Limestone (top of Kaibab at 952 msl)	2199	
Sec20 T22S R60E	2631	1107	1524	2210	Bird Spring Fm.	686	
Sec20 T22S R60E	2800	none	707	707	none		

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec21 T15S R67E				575	no log		
Sec11 T17S R64E	2120			1002	no log		lost circulation at 1002
Sec18 T17S R65E				3302	no log		
Sec6 T18S R64E	2380	none	1247	1247	none		
Sec7 T18S R64E	2041	none?	1455	1455	no log, none(?) (probably did not drill out of valley fill)		
Sec2 T21S R62E	1650			1970	no log		well penetrated hot water beds which could not be cased off
Sec2 T21S R62E	1650			2268	no log		
Sec22 T21S R56E	5310	4100	1210	2602	limestone & dolomite	1392	
Sec27 T22S R60E				2020	no log		
Sec26 T24S R58E	3695	3258	437	716	Kaibab(?)	279	
Sec34 T25S R60E				580	no log		
Sec17 T23S R61E	2675			300	no log		
Sec17 T23S R61E	2000?	840?	1160?	1180	Miss.(?) (Monte Cristo gr.?) incomplete log	20	
Sec30 T22S R63E	2204			2300	no log		
Sec32 T22S R63E	2100			810	no log		
Sec32 T22S R63E	2100			1465	no log		encountered water that could not be controlled @1465'
Sec8 T28S R62E	4300			840	no log		
Sec13 T23S R60E	2860	2845	15	2002	Bird Spring Fm.	1987	

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Lincoln County							
Sec18 T12S R65E	3693			7030	no log		lost circulation @613', 1100', 1400', 1520', 2200'
Sec19 T7N R64E	6037	-593	6630	7024	Paleozoics (Ely group)	394	
Sec29 T7N R63E	6200	6187	13	488	Ely Limestone	475	Water @288'
Sec22 T9N R63E	6540			6264	no log		
Sec17 T1S R60E	4948			2434	no log		
Nye County							
Sec25 T10N R57E	4990	-60	5050	5556	Devonian	506	
Sec22 T9N R56E	4770			4840	no log		
Sec10 T7N R56E	4708	-2218	6926	7120	Paleozoic	194	
Sec5 T6N R56E	4716	-1638	6354	6553	Joana Ls. (Miss.)	199	
Sec1 T6N R55E	4729	1224	3505	4130	Paleozoic (Dev.?)	625	
Sec6 T6N R57E	4777	2047	2730	3138	Paleozoic (Dolomite)	408	Porous zone in dolomite 2730-2805'
Sec4 T7N T62E	5365	-215	5580	7000	Ely Ls. (Penn.) *ls. & dol. at 2965 msl	1420	
Sec30 T10N R62E	5496	3774	1695	4092	Ely Ls. (Penn.)	2397	
Sec17 T8N R62E	5437	-1106	6543	7067	Ely Ls. (Penn.)	524	
Sec33 T6N R61E	5202	2252	2950	5690	Ely Ls. (Penn.)	2740	
Sec7 T6N R62E	5284	1618	3666	3980	Penn. (Ely Ls?)	314	
Sec17 T7N R57E	4717	-1577	6294	7188	Ely Ls. (Penn.)	894	
Sec29 T5N R55E	4809			7780	incomplete log		DST - recovered fresh water 3920-4170'

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec9 T9N R61E	5324	-204	5528	6150	Paleozoic (?)	622	porous zone 5630-5846'
Sec33 T8N R61E	5255	2040	3215	4350	Penn. (Ely Ls. ?)	1135	vuggy limestone 3386-3396, fracture porosity 3645-3767'
Sec36 T10N R57E	4925		8413	8413	none (Sheep Pass Fm.)		
Sec2 T11N R57E	5748			2943	no log		
Sec36 T3N R54E	6415			8355	no log		
Sec4 T5N R56E	4820			4820	no log		heavy water flow 1295-4820'
Sec33 T9N R56E	4755			4225	no log		
Sec28 T7N R55E	4611	3301	1310	1711	Paleozoic limestone & dolomite	401	lost circulation 1386', 1415-1458'
Sec2 T7N R56E	4709	-5446	10155	10183	Paleozoic	28	
Sec27 T8N R57E	4743	-451	5194	6038	Simonson Dolomite (Devonian)	844	
Sec22 T8N R57E	4729	-2565	7294	7885	Simonson Dolomite (Devonian)	591	
Sec34 T9N R57E	4742	none		9518	none		
Sec5 T7N R57E	4714	-3529	8242	8587	Paleozoics	345	
Sec4 T7N R57E	4720	-315	5035	7485	ls., dol., & sh.	2450	
Sec26 T9N R57E	4778	none		8300	none (Sheep Pass Fm.)		7860-7862.5' major fractures in limestone
Sec35 T9N R57E	4718	none		7805	none (Sheep Pass Fm.)		
Sec3 T8N R56E	4732	none		7324	none (volcanics)		
Sec7 T8N R57E	4726	none		13832	none (volcanics)		
Sec5 T8N R60E	6180	none		800	none (miss.)(Diamond Peak Fm.)		

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec4 T8N R61E	5301			6333	(?) two logs		
Sec31 T10N R57E	4820			3800	no log		
Sec34 T9N R57E	4747	-3835	8582	8694	Paleozoics (Ely Ls.?)	112	
Sec34 T9N R57E	4745	none		8044	none (volcanics)		
Sec35 T9N R57E	4746	none		7500	none		
Sec36 T9N R57E	4790	none		7566	none (Sheep Pass Fm?)		
Sec35 T9N R57E	4768	-1320	6088	8485	Paleozoics	2397	
Sec36 T9N R57E	4838	-789	5627	5670	Paleozoics	43	
Sec30 T9N R58E	4867	781	4086	4420	Paleozoics	334	
Sec8 T10N R58E	5200	none		620	none		
Sec28 T11N R60E	6610	6610	0	692	(Penn.?)or(Miss.?), ls. surface to TD	692	
Sec36 T9N R57E	4838	-662	5500	7195	Paleozoic (?)	1695	
Sec1 T8N R57E	4784	-284	5068	5204	Paleozoics	136	
Sec36 T9N R57E	4818			6771	no log		
Sec8 T10N R58E	5200	none		402	none		
Sec17 T12N R47E				4353	no log A.E.C. well		
Sec10 T11N R49E				3295	no log A.E.C. well		
Sec22 T10N R51E				7978	no log A.E.C. well		
Sec33 T10N R60E				750	no log		
Sec2 T7N R61E	5255			10473	no log		
Sec13 T9N R57E	4820			9040	no log		

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec33 T8N R53E				6500	no log A.E.C. well		
Secl T8N R52E				6495	no log A.E.C. well		
Sec34 T9N R51E				6000	no log A.E.C. well		
Sec22 T10N R49E				2963	no log A.E.C. well		
Sec 36 T3N R54E				8300	no log		
Sec3 T3N R57E				8500	no log Kock Tertiary test (wildcat)		
Sec31 T8S R53E				5940	no log A.E.C. well		
Sec18 T9S R53E				3896	no log A.E.C. well		
Secll T7S R49E				8782	no log A.E.C. well		
Sec3 T8S R48E				13685	no log A.E.C. well		
Sec21 T10S R53E				3026	no log A.E.C. well		
Sec30 T12S R54E				2124	no log A.E.C. well		
Sec34 T9N R56E	4740			6368	no log		
Sec27 T9N R56E	4750			4865	no log		
Eureka County							
Sec6 T26N R51E	5640			3612	no log		
Secll T27N R52	5610	none	1205	1205	none Tertiary surface to T.D.		
Sec6 T26N R52E	5745	none	3116	3116	none Tertiary volcanics		
Sec3 T27N R52E	5450			4905	no log		
Secll T27N R52E	5693			1848	no log probably Tertiary Volcanics		

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec32 T28N R52E	5284	none	10505	10505	none - Volcanics		
Sec6 T26N R51E	5496			3549	no log		
Sec30 T23N R54E	5823	-1677	7500	8042	Paleozoic (Dev. NV Fm.)	542	
Sec27 T27N R50E	5675	none	420	420	none - Tertiary surface to T.D.		
Sec27 T27N R50E	5585	none	1024	1024	none - Tertiary surface to T.D.		
Sec27 T27N R50E	5600	2480	3120	3828	Permian	708	
Sec34 T17N R50E				1579	no log A.E.C. well		
Lander County							
Sec34 T32N R45E	4537			3456	no log		
Sec34 T32N R45E				3178	no log		
Sec27 T32N R45E	4537	none	912	912	none		
White Pine County							
Sec35 T23N R58E	6330			7084	no log		
Sec19 T10N R62E	5625	none	3581	3581	none (Sheep Pass Fm.)		lost circulation @3581'
Sec27 T11N R61E	5420	51	5369	5895	Joana Ls. (Miss.)	526	
Sec35 T23N R58E	6224	4959	1265	7020	Permian	5755	many zones of lost circulation and fractures
Sec10 T10N R61E	5382	2372	3010	4957	Ely Ls. (Penn.)	1947	
Sec9 T14N R61E	6210			4600	no log		
Sec17 T19N R64E	6186			6100	no log		fresh water @5115-5264, 5985-6100'

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec14 T20N R61E	6266			2978	no log		
Sec30 T16N R64E	6586			2690	no log		
Sec30 T16N R64E	6407			3253	no log		water @2632-2867'
Sec20 T26N R70E	5504	3289	2215	4498	Gerster (Permian) Fm.	2283	cavernous & vuggy Ls. 2258-2261', many other similar zones
Sec11 T17N R58E	6200	none	929	929	none-Chainman Sh.		
Sec8 T15N R63E	8200	none	780	780	none-Chainman Sh.		water @450'
Sec28 T20N R59E	6433			6428	no log		
Sec25 T11N R63E	6510	1710	4800	5015	Ely Ls.(Penn.) "probable top"	215	
Sec19 T24N R64E	5864	-1006	6870	8406	Paleozoics	1536	
Sec31 T16N R56E	6403	2440	3963	10314	Guilmette Ls. (Dev.)	6351	lost circulation @4478', 4673'
Sec32 T20N R60E	7260	7260	0	11543	Arcturus (Permian) gr.	11543	many zones of lost ciruclation & fractures
Sec19 T10N R62E	5486	1041	4445	4850	Ely Ls. (Penn.)	5	
Sec23 T18N R57E	6588	3765	2823	7980	Joana Ls. (Miss.)	5157	water @2835-2940', circulation problems 3386'
Sec5 T15N R57E	6675	5125	1550	2681	Guilmette Fm. (Dev.)	1131	lost circulation 2555-2625', 2653-2681'
Sec34 T22N R59E	6750	none	365	365	none, Diamond Peak Fm. to T.D.		
Sec25 T21N R60E	6360	none	956	956	none, Diamond Peak Fm. Ely Ls. from 20-250'?		
Sec16 T19N R61E	6580	6560	20	712	Ely Ls. (Penn.)	692	
Sec17 T15N R59E	7361	7361	0	5117	Ely Ls. (Penn.)	5117	cavernous zone 4058-4097' with two 9', a 3' & a 2' opening many zones of lost circulation
Sec32 T18N R58E	7600	none	920	920	none ? (Miss.)(Chainman Shale ?)		

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec22 T13N R61E	5960	5940	20	1234	Ely Ls. (Penn.)	1214	
Sec21 T18N R58E	7520	6650	970	7620	Joana Ls. (Miss.)	6650	
Sec14 T14N R60E	6550	5700	950	3742	Ely Ls. (Penn.)	2792	
Sec9 T14N R61E	6210			271	no log		
Sec4 T14N R61E	6180	none	2603	2603	none		water flow @660' from fracture
Sec14 T14N R60E	6550	none	696	696	none		
Sec32 T22N R63E				1465	no log		
Sec20 T22N R61E				1000	no log		
Sec34 T22N R58E				9000	no log		
Sec27 T20N R63E				9263	no log		
Sec21 T19N R63E				4407	no log		
Sec35 T21N R60E				6500	no log		
Sec14 T20N R60E				11531	no log		
Sec1 T14N R60E				1660	no log		
Sec9 T10N R62E				4850	no log		
Sec11 T17N R58E	6920	6100	820	1572	Joana Limestone?	752	

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Pentrated (feet)	Comments
Elko County							
Sec34 T38N R62E	5611			4205	no log		
Sec10 T27N R54E				804	no log		
Sec15 T26N R54E				1072	no log		
Sec3 T27N R54E				165	no log		
Sec3 T27N R54E				565	no log		
Sec4 T34N R55E				3337	no log		
Sec36 T30N R64E	5850	5555	295	3158	Gerster Ls. (Permian)	2863	
Sec16 T41N R60E	5962	-513	6475	6612	Kinikinic quartzite (Ordovician)	137	
Sec18 T28N R70E	5600	4340	1260	1546	Miss. (Joana Ls.?)	286	
Sec3 T37N R59E	5505	2187	3318	5465	Paleozoics	2147	
Sec8 T40N R66E	5650	none		8412	none		
Sec21 T38N R61E	5589	-2444	8033	8416	Paleozoics	383	
Sec19 T39N R69E	4889	182	4707	4938	Paleozoics	231	
Sec31 T36N R58E	5500			980	no log		
Sec31 T36N R58E	5500			980	no log		

APPENDIX IV (cont.)

Location	Surface Elevation (feet msl)	Elevation of Top of Carbonate (feet msl)	Thickness of Alluvium (feet)	Total Depth of Well (feet)	Formation or Age of Top of Carbonate	Thickness of Carbonate Penetrated (feet)	Comments
Sec31 T36N R58E	5500	none		324	none		
Sec31 T40N R55E	6050	1860	4190	7106	Paleozoics	2916	
Sec16 T34N R55E	5132			5670	no log		
Sec23 T31N R69E			590	1327	Permian (?)		
Sec9 T35N R58E	5250	2100	3150	4125	Penn. (Ely Ls.?)	975	
Sec3 T37N R67E	5890			5284	no log		
Sec8 T30N R60E	5952	2062	3890	13116	Permian	9226	recovered large volumes of water during 3 DST, circulation problems
Sec19 T29N R56E	5550	none	13600	13600	none, Tertiary to T.D.		
Sec11 T34N R57E	5308	2238	3070	7349	Paleozoics	4279	several zones of lost circulation
Sec22 T43N R52E	6101	3751	2350	3386	Paleozoics	1036	
Sec19 T32N R67E	5600	320	5280	5569	Permian	289	
Sec14 T31N R69E			785	785	Paleozoic (?)		
Sec21 T43N R52E		none	800	800	none		
Sec4 T40N R52E				5000	no log		

APPENDIX IV (cont.)